Developmental Differences in Endogenous Control & Attentional Capture

Rumandeep K. Hayre BSc., MSc.

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Thesis Abstract

Aims: The ability to plan-ahead allows us to focus our attention at an early stage of processing and is said to facilitate our ability to ignore distractions. This thesis aimed to track the development of *endogenous control* across the lifespan and assess if this skill can prevent attentional capture from a *salient* distraction. I used the Cued Visual Search task to understand whether children and adults can maintain early cues to guide their attention towards a target and suppress a salient distracter.

Chapters 2-7: In Chapter **2**, I designed and validated whether a shape singleton distracter could produce attentional capture. I included this item in the Cued Visual Search task introduced in Chapter **3** where I compared children's (5-6 & 9-11 years) and young adults' performance when endogenous cue-utilisation was encouraged vs discouraged. In Chapter **4**, I examined the possibility of cross-colour priming effects within the Cued Visual Search task. Chapter **5** considered the role of block predictiveness for encouraging endogenous cue-use in children. In Chapter **6**, I assessed if this skill is used similarly in the Cued Visual Search task and the AX-Continuous Performance Task in young and older adults. Chapter **7** manipulated search difficulty for a complex target to enhance cue-use and reduce capture.

Conclusions: The results suggest that endogenous control is still developing in early-childhood (5-6 years) but becomes adult-like by mid-childhood (9-11 years) and does *not* decline in seniority. Immature forms of this skill (5-6 years) are able to maintain an early task-goal but it is less effective under highly distracting situations. Indeed, this domain-specific skill is enacted differently depending on the demands of the task. Contrary to predictions, endogenous cue-utilisation was unable to prevent attentional capture at an early point in processing in children and adults but was reduced at a late point in processing. One reason for this could be due to the independence found between maintenance and inhibition abilities in Cued Visual Search from mid-childhood and onwards. Endogenous cues may create a variable task-goal that changes on a trial-by-trial basis, which make it difficult to suppress a distraction at an early stage of processing but this may reactivate the task-goal in the moment to avoid further capture. Overall, this thesis emphasises the development and limits of endogenous cue-utilisation for selectively focusing our attention.

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Paper Submissions & Presentations

Paper Submissions

Areas in Chapter 1 and the majority of Chapter 3 are adapted from the paper which is currently under review with Acta Psychologica:

Hayre, R. K., Cragg L., & Allen, H. A. (under review). *Endogenous Control is Insufficient for Preventing Attentional Capture in Children and Adults*.

Conference Presentations

Chapter 2 and Chapter 3 have been presented at the following conferences:

Oral Presentation:

British Psychological Society (BPS) Developmental and Cognitive Psychology 2019

Poster Presentation:

Applied Vision Association (AVA) Spring Meeting 2019

Society for Research in Child Development (SRCD) Virtual Biennial Meeting 2021

Public Engagement

The findings from the following chapters were discussed at these events:

Chapter 2 & 3:

School Newsletters in three schools in Derbyshire

UoN Ambition Nottingham 2018 & 2019 – Prospective Students aged 16-17 years

UoN Core Maths 2018 & 2019 – Students aged 14-15 years

Chapter 5:

Summer Scientist Week (in-person) and Newsletter 2018/19

Chapter 6:

UoN Webinar 2021 – How do we see depth and focus attention as we get older?

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Chapter 1: General Introduction

The attentional system is a dynamic and complex structure. To focus our attention on a particular topic or object in our environment is a highly effortful skill. In everyday life we often embark on our activities with plans and goals in mind. Whether that is when we are commuting, buying groceries or studying for an upcoming exam, we regularly find ourselves planning ahead. This ability is also referred to as *top-down, proactive* or *endogenous control*; a higher-order process which enables us to direct our attention towards goal-relevant objects and away from goal-irrelevant objects (Braver, 2012; Desimone & Duncan, 1995; Soto, Hodsoll, Rotshtein & Humphreys, 2008). At the same time, our attention can be distracted away from our tasks by irrelevant and eye-catching features in our environment (Theeuwes, 2010). This is a common everyday occurrence which happens often in classroom learning environments (Fisher, Godwin & Seltman, 2014; Godwin & Fisher, 2011). Indeed, distractibility from a young age has been shown to impact both school readiness and classroom learning as well as attainment in later childhood (Erickson, Thiessen, Godwin, Dickerson & Fisher, 2015; Steele, Karmiloff-Smith, Cornish & Scerif, 2012; Isbell, Calkins, Swingler & Leerkes, 2018; for a review see Heim & Keil, 2012). It is argued that children are more susceptible to distractions than adults (Gaspelin, Margett-Jordan & Ruthruff, 2015; Iarocci, Enns, Randolph & Burack, 2009). Recent research suggests that during childhood, children develop the ability to utilise endogenous (top-down) cues in their environment (Leclercq & Siéroff, 2013; Shimi, Nobre, Astle & Scerif, 2014; Wainwright & Bryson, 2005). Yet little research has investigated how children's use of this attentional control mechanism compares to adults, whether it can be used to ignore eye-catching distractions and how this ability relates to inhibition abilities.

The main aim of this thesis is to investigate the developmental differences in endogenous cue-utilisation in children and adults. Endogenous cues provide information at an early point in processing to enable us to anticipate an upcoming event or stimulus (Posner, 1980; Posner & Cohen, 1984). Second, this thesis aims to understand whether endogenous cues can influence the ability to inhibit an eye-catching or *salient* distraction. The study of endogenous control and its role in preventing attentional capture from distractions has been heavily reported in the adult literature (Gaspelin, Leonard & Luck, 2015, 2017; Gaspar & McDonald, 2014), but less is known in developmental and aging populations. Even more scarcely, it is questionable whether enhancing a target-signal by *cueing* a feature of the target, can inhibit a distracter-signal which demands attention. Third, I aim to assess the general relationship between maintenance and inhibition abilities in Cued Visual Search. Maintenance of an instruction or cue can enable us to establish a top-down goal to up-regulate attention signals towards particular items (e.g. a target) in our visual field (Soto et al., 2008). Inhibition at the perceptual level can allow us to down-regulate the signal from an item (e.g. a distraction) within our visual field to enable us to redeploy our attention elsewhere (Theeuwes, 2010). The interaction between maintenance and inhibition has been heavily overlooked, despite both being acknowledged as key components in visual orienting (Brodeur & Boden, 2000; Van der Stigchel, Meeter & Theeuwes, 2007). By taking a developmental perspective to explore these aims, I will be able to draw comparisons between immature and mature forms of endogenous control to understand the limits of this skill on the inhibition of distraction at different stages across the lifespan.

In this chapter, I will first discuss the main theories of attentional selection and endogenous control. I will focus specifically on the interaction between top-down and bottom-up processing when searching for a target. Next, I will review our understanding of attentional capture from irrelevant items in our environment. Finally, I will consider the relationship between endogenous cue-utilisation and attentional capture. Specifically, whether a bottom-up signal can be overcome by an intentional top-down process is questionable and even more so, it is scarcely understood how age influences this dynamic.

Endogenous Control

Endogenous control is considered as a volitional process which influences our ability to locate objects in our environment as well as orient and selectively focus our attention (Ruz & Lupiáñez, 2002). In this section, I will first define endogenous control by discussing the relevant theoretical and neural underpinnings involved in this higher-order skill. Emphasis of this knowledge will be applied to the Cued Visual Search task; a well-known measure of visual orienting behaviour renowned for its ability to compare bottom-up and top-down processes in selective attention. Finally, I will consider the role of development and aging on endogenous cue-utilisation and draw comparisons between Cued Visual Search and other experimental paradigms which have assessed this skill.

Theoretical Mechanisms

Early accounts of visual attention first proposed that attentional guidance is based on bottom-up feedback concerning the physical distinctiveness between items in our visual field. The Feature Integration Theory (Treisman & Gelade, 1980) first described attentional deployment in search behaviour across two levels of processing. It suggested that visual information is processed with regards to its *features* at different dimensions (for instance, colour, orientation and shape). This theory posited that featural information is processed at two sequential levels: 1) the preattentive level and 2) the attentive level. The preattentive level is said to have a large capacity and enables us to process featural information in *parallel* and without attentional deployment across the whole visual field. At this level, feature maps are created to activate each feature of an item in the search-display with its associated location. For instance, take the example of a search-display which consists of a circle target amongst square non-targets. Feature maps would activate shape information (circle and squares) associated with each location in the search-display. In this case, the circle target would be located at the preattentive level as its shape feature is distinguishable from the square non-targets. If a target cannot be distinguished from non-target items at the preattentive level, it is further processed at the attentive level. Additionally, the attentive level is theorised to have a limited capacity and requires attentional resources for *feature binding* to take place, whereby information from individual feature maps are combined. This would ensure that the target is detected *serially*, by deploying attention to each individual item in the search-display until the target is located. Supporting evidence indicated that search was deployed in a parallel fashion when participants were asked to search for a “Q” letter target amongst “O" non-target items, whereby the “Q” target was distinguishable by activation of an orientation feature map (Treisman & Gormican, 1988; Treisman & Souther, 1985). Therefore, this early account of visual attention posits that attention can be engaged towards a target without the deployment of attentional resources in an *exogenous* fashion, if bottom-up feature information ensures that the target item is distinguishable in a single dimension from other items in the search-display.

Revisions to this early account of visual attention have been made to encompass the role of top-down processes at the preattentive level of search. Indeed, search behaviour is often regarded as incorporating both bottom-up and top-down processes to guide attention towards an item for identification (Soto et al., 2008). The Guided Search model (Wolfe, Cave & Franzel, 1989; Wolfe, 2014) suggests that maintenance of an early task-goal (e.g. search for the circle target) can bias attention towards goal-relevant features (e.g. circle items) in our visual field. By establishing a task-goal at an early point in processing (i.e. before seeing an upcoming item), this can allow us to prepare our attentional resources as opposed to responding to the stimulus at a late stage of processing (i.e. after seeing the item). This theory draws on other attentional selection accounts (Bundesen, 1990- Theory of Visual Attention; Desimone & Duncan, 1995 – Biased Competition Model; Found & Müller, 1996 – Dimensional Weighting Account) which posit that our maintained task-goals can be used to assign attentional weights to characteristics in our feature maps at an early point in processing. For instance, search for a circle target will be assigned a greater weight for activating this feature relative to other non-target features in the search-display. As a result, a master feature map is created which can analyse the relationship between the target and non-target features with specific regard to its bottom-up characteristics or *saliency*. The feature which has the largest amount of saliency from its combined bottom-up and top-down attentional weight plays the dominant role in guiding attention towards it and away from irrelevant items.

This account provides a consensus with Treisman and Sato's revised Feature Integration Theory (1990) in suggesting that maintenance of an early task-goal can lead to the inhibition of features which are task-irrelevant or meet the criteria for rejecting a task-irrelevant attentional template. This also agrees with Duncan and Humphreys (1989) who theorised that perceptual grouping of non-target items, which do not include a feature of the task-goal, can lead to inhibition of these items. Empirical evidence provides support for guided search at the bottom-up and top-down level described by this "winner take all" principle. Search is facilitated when a featural target, defined by a single feature in one dimension, is presented within a heterogeneous display of non-targets (e.g. circle amongst hexagons, pentagons & squares) relative to a homogenous display (e.g. circle amongst squares; Bacon & Egeth, 1994; Gaspar & McDonald, 2014; Gaspelin et al., 2017; Humphreys, 2016). In a heterogenous display of non-target items, maintenance of the task-goal is encouraged as search cannot be guided in a bottom-up fashion based purely on searching for the "pop out" target as is the circumstance in a homogenous display of non-target items. Therefore, attentional guidance can be understood as a dynamic between top-down and bottom-up processes, whereby maintenance of an early task-goal can be used to bias attentional resources towards task-relevant items within a search-display and away from task-irrelevant items.

Similarly, the Dual Mechanisms of Control theory (Braver, 2012) suggests that there are two modes of cognitive control which influence our thoughts, actions and attention. Proactive control is similar to the definition of endogenous (top-down) control, in that maintenance of a task-goal is theorised to bias attention at an early point in processing (i.e. before seeing an upcoming item) to anticipate an impending event. In contrast, reactive control is similar to exogenous (bottom-up) control, as the task-goal is not maintained but rather reactivated in the moment that it is required at a late stage of processing (i.e. after seeing the item). This model specifies that the maintenance and manipulation of a task-goal is related to working memory, whereby those with smaller capacities in this skill maintain task-goals less robustly relative to high-capacity individuals (Engle, 2010; Redick, 2014; Redick, Calvo, Gay & Engle, 2011). This may correspond with the understanding that effective maintenance of an early task-goal allows users to allocate attention selectively to task-relevant stimuli in a context interleaved with task-irrelevant distracters; a process which low-capacity individuals may have difficulty with (Engle & Kane, 2004; Fukuda & Vogel, 2009, 2011).

The ideas proposed in attentional control and cognitive control theories hold stark similarities in describing how attention can be guided to form an expectancy for an upcoming event. Revisions to Feature Integration (Treisman & Sato, 1990) and Guided Search (Wolfe et al., 1989; Wolfe, 2014) suggest early maintenance of a task-goal can lead to enhanced attentional selection for task-relevant features and inhibition of task-irrelevant features. In correspondence with this, the Dual Mechanisms of Control theory (Braver, 2012) proposes proactive control can guide attentional resources at an early point in processing. This theory further specifies that maintenance of task-goals may be related to working memory. Overall, different accounts of attention suggest there is a dynamic between bottom-up and top-down processes, with the latter process theorised to play a dominant role in guiding search given robust maintenance of an early task-goal.

Cued Visual Search Task

The mechanisms described in the aforementioned theories of attentional selection have been applied to understand the role of endogenous cues in guiding attention. The Cued Visual Search task provides participants with a cue to guide attention at an early point in processing. There are many variants of this task whereby the cue can provide information concerning the spatial position (i.e. location or spatial cue) or feature of the upcoming target (i.e. feature or central cue). In the latter case, participants are asked to search and respond to a target within the search-display. Prior to this, the cue can either inform them (e.g. valid cue – pink cue guides attention towards target in pink), misinform them (e.g. invalid cue – blue cue guides attention away from target in pink but towards non-target in blue) or does not inform them (e.g. neutral cue – green cue does not guide attention as green items are absent from the search-display, target in pink) about the upcoming feature of the target (for a review, see Soto et al., 2008). If the cue guides attention, this results in the finding of a *cueing effect* which shows that search is faster and more accurate on valid trials relative to neutral trials (cue benefit on performance), whereas search is slower and less accurate on invalid trials relative to neutral trials (cue cost on performance; Carlisle & Woodman, 2011; Greenwood & Parasuraman, 2004; Hayward & Ristic, 2013; Kiyonaga, Egner & Soto, 2012; Posner, 1988; Soto & Humphreys, 2007).

A cueing effect can suggest maintenance of the cued information which may have enhanced the attentional weight given to this feature to guide search in a top-down or *endogenous* manner. This can result in better performance when the cue correctly biases attention towards a matching target on valid trials, but worse performance when attention is misallocated on invalid trials and the non-target must be inhibited to disengage attention from this item before serially searching for the target (Posner, 1980; Treisman & Sato, 1990; Wolfe, 2014). Interestingly, cue maintenance in the Cued Visual Search task, has been associated with visual working memory capacities (Hahn & Buttacio, 2018; Soto & Humphreys, 2007; Won & Jiang, 2015). Specifically, increases in visual working memory load has been shown to interfere with maintenance of symbolic central and verbal cues (Won & Jiang, 2015). Recall of the cued information following search has also been found to enhance cue maintenance relative to mere attendance of this information (Soto et al., 2008). Overall, cue maintenance can increase the signal for featural information related to the target at an early point in processing.

The Cued Visual Search task can be used to disentangle and compare exogenous (bottom-up) and endogenous (top-down) processes in guided search. Manipulation of the proportion of trial types across a block has been found to affect the attentional control mechanism utilised to guide search in this task. Evidence has shown cueing effects to be significantly greater in a mostly predictive block condition, where the majority of trials are valid, compared to an unpredictive block (Laarni, 2001; Leclercq & Siéroff, 2013). If the cue is unpredictive of the target's location (i.e. valid : invalid trials proportion is at chance levels or all trials are neutral), guided search is based on exogenous orienting from the cued information (Leclercq & Siéroff, 2013; Milliken, Lupiáñez & Stevanovski, 2003; Ristic & Kingstone, 2012). In this situation, attentional guidance is a consequence of a reflexive response based on merely attending to the bottom-up features of the cue. This will be discussed in more detail in the next paragraph. In contrast, if the cue is predictive of the target's location (i.e. valid : invalid proportion is at ~70% : 30% or higher), participants are encouraged to maintain this early cue to endogenously orient attention (Mayer, Dorflinger, Rao & Seidenberg, 2004; Soto & Humphreys, 2007). It is argued that a mostly predictive block can establish a task-goal which can encourage cue-utilisation to be sustained across the block of trials, as opposed to short interludes of cue-use within the block (Laarni, 2001; Mayer et al., 2004). Therefore, learned predictiveness associated with the cue can influence whether this information is maintained to guide search as well as ensure comparisons can be made between exogenous and endogenous orienting.

In addition to the learned predictiveness of the cue, the type of cue can also influence the task demands in disentangling orienting processes. Central or featural cues (arrows, colour, shape) are often used for measuring endogenous orienting as this information requires interpretation and maintenance to anticipate the upcoming feature of the target (Hamker, 2004; Nothdurft, 1993). In contrast, spatial or location cues appear as an item or luminance change at a specific location within the search-display (Iarocci et al., 2009). These types of cues are often defined as exogenous as they are 1) difficult to ignore (automatic process), 2) yield larger cueing effects than endogenous cues when briefly presented and 3) are less affected by learned expectancies concerning the predictiveness of the cue (Berger, Henik & Rafal, 2005; Jonides, 1981). Indeed, exogenous cues are also known to create maximal cueing effects at short (100 – 200ms) cue-target stimulus onset asynchronies (SOAs) but at later SOAs (above 200ms), anti-cueing effects or *inhibition of return* (slower valid vs invalid trials) is found (Berger et al., 2005; Posner & Cohen, 1984; Shepherd & Müller, 1989). Importantly, anti-cue effects are often found in search-displays where the target could appear in one of two locations (Cheal & Chastain, 2002; Corbetta, Kincade, Ollinger & McAvoy, 2000). In this respect, an anti-cue effect is arguably a consequence of endogenous control (Rosen et al., 1999), as participants can learn that the mostly unpredictive cue is in fact informing them where the target is *not* (i.e. cue on the right interpreted as, target will appear on the left). The provision of longer SOAs ensures participants have time to prepare an inhibitory response to the reflexive cue, as shown by enhanced activation in the frontal eye fields and temporo-parietal junction; regions which have been shown to be associated with endogenous but not exogenous orienting (Corbetta et al., 2000; Mayer et al., 2004; see Box 1 for further information on the neural processes involved in orienting). Therefore, methodological elements of the Cued Visual Search, particularly learned predictiveness and the cue type, can interact to play a significant role in the attentional control mechanism employed to guide search.

I plan to use colour cues in my research to guide attention at an early point in processing in the Cued Visual Search task. Maintenance of an early task-goal or cue holds merit in computational accounts of feature-based attention (Hamker, 2004). The use of colour for directing attention is known to produce strong global effects for biasing attentional resources towards matching items across the visual field (Laarni, 2001; Andersen, Müller & Hillyard, 2011). It is argued that bottom-up feature maps are first encoded in the extrastriate region V4 as part of the ventral “what” stream. This information is fed forward to the inferior temporal cortex, an area which is

Box 1. Neural Processes in Exogenous and Endogenous Orienting

Endogenous orienting has been linked with activation in the fronto-parietal network (Corbetta & Shulman, 2002; Serences & Yantis, 2006). In particular, activation in the occipital area in the extrastriate (V4) regions is thought to reflect bottom-up encoding of featural cues (Mayer et al., 2004). Maintenance of endogenous (but not exogenous) cued information has been associated with increased activation in the lateral prefrontal cortex and frontal eye fields (Rosen et al., 1999). Regions in the posterior parietal cortex, particularly the intraparietal sulcus, have also been regarded with their involvement in cue maintenance, selective responses to task-relevant features which match the attentional template or cue and down-regulating task-irrelevant features (Gottlieb & Snyder, 2010; Mevorach, Hodsoll, Allen, Shalev & Humphreys, 2010; for a review, see Shomstein & Gottlieb, 2016). Posterior parietal regions have also been involved in the calculation of saliency and so this area is both impacted by bottom-up and top-down modulations (Li, Gratton, Yao & Knight, 2010). When attention is invalidly cued however, a reorienting response towards unattended items to further search for the target, has been associated with increased Blood Oxygen Level Dependent (BOLD) responses in the temporo-parietal junction (Corbetta et al., 2000). Comparisons of orienting responses on valid trials has shown enhanced activations in the aforementioned fronto-parietal regions, particularly the prefrontal areas, for endogenous cues relative to exogenous cues (Kim et al., 1999; Li et al., 2010; Mayer et al., 2004). This suggests that there is some overlap in the regions of interest with the fronto-parietal network but endogenous control requires more effortful shifts in attentional resources compared to reflexive shifts in exogenous control.

modulated by the maintained task-goal or cue, before feeding this information back to V4 to inform about the task-relevant stimuli. For instance, in a context where the cue is highly predictive of the target's location, participants are expected to be encouraged to maintain cued information in the lateral prefrontal cortex, frontal eye fields and posterior parietal cortex. A pink cue forms the implicit task-goal to anticipate a pink target and so upon onset of the search-display, feature maps are encoded based on their bottom-up properties (Sawaki & Luck, 2010). Following this, information from the posterior parietal cortex and prefrontal regions concerning the task-goal (i.e. look for the target in pink) is fed back to the inferior temporal cortex.

Excitatory responses to features are said to be modulated by the task-goal (Hamker, 2004) and so the gain for a population of cells encoding pink in this region, is enhanced by the expectation that the target will appear in pink. In contrast, features which do not match this task-goal (e.g. green) are argued to be suppressed at this level of processing. This information concerning the task-relevant stimuli in the search-display is reentered to V4 to enable prioritisation of visual processing for this stimuli (i.e. pink items) and action is guided to make an anticipatory saccadic response based on activity in the frontal eye fields to task-relevant features (Corbetta & Shulman, 2002). This process of events transpiring in colour cueing, suggests that cue maintenance enhances the signal for task-relevant features. This then reduces the signal for task-irrelevant or distracter features to facilitate guided search.

Based on the points discussed, it is understood that the Cued Visual Search task is a valid measure for separating exogenous and endogenous control processes. Behavioural and neural evidence has shown that manipulation of the task demands, particularly learned predictiveness of the cue, can reliably modulate the form of control used to guide search towards a target (Berger et al., 2005; Corbetta et al., 2000; Jonides, 1981; Mayer et al., 2004). The type of cue also plays a significant role as central feature cues, such as colour, can lead to enhanced endogenous maintenance of this early information (Hamker, 2004; Laarni, 2001). The influence of age on the processes discussed have been examined in a number of experimental paradigms, including Cued Visual Search. Next, I will examine this literature and pay particular attention to the methodological limitations which arise from the findings.

Endogenous Control: Developmental & Aging Effects

Age-related changes in endogenous control have been theorised to follow an inverted “U” curve, whereby attentional control qualitatively shifts from using mainly exogenous control to using mainly endogenous control during childhood (5-11 years) (Munakata, Snyder & Chatham, 2012; Lorsbach & Reimer, 2011). In later life, this form of control is posited to revert back to the main use of exogenous control in older adulthood (Braver, Paxton, Locke & Barch, 2009; Humphrey & Kramer, 1997). This pattern of age-related changes has mixed findings across different measures of endogenous cue-utilisation however. I will discuss the main points from this field to understand the developmental trajectory of this skill across the lifespan.

Some research has indicated that children aged five and six have developed the ability to utilise endogenous control to guide their behaviour. In studies using the cued task-switching paradigm, children aged five to six and eight to nine years were asked to use a cue to help them switch between sorting animal stimuli by colour (first task-goal) or shape (second task-goal) (Chevalier, Martis, Curran & Munakata, 2015; Chevalier, Meaney, Traut & Munakata, 2020). It was found that all children were faster at switching between task-goals and also showed enhanced cue-related pupil dilation when they were encouraged to maintain the cue (i.e. cue briefly presented) before the onset of the target. Unlike eight- to nine-year-olds, five- to six-year-olds did not show this effect when the cue remained on the screen during target-onset. Research using event-related potentials (ERP) adds to these findings by showing five-year-olds had greater cue-P3 amplitudes and slow-wave amplitudes (suggestive of cue-maintenance) on switch-trials (Elke & Wiebe, 2017; Chevalier et al., 2015, 2020). This shows that children in early- to mid-childhood were able to interpret and maintain the cue in order to anticipate the next task-goal to sort the target by. In particular, Chevalier et al. (2015) suggested that the brief presentation of the cue encouraged early maintenance in young children as retrieval of this information was made more difficult, relative to relying on the ongoing presentation of the cue throughout a trial. They also added that cue-maintenance is influenced by learned predictiveness, as both six- and nine-year-olds only engaged endogenous control when all of the cues informed them of the task-goal to switch to, relative to the uninformative block (50% of cues informative) (Chevalier et al., 2020). Altogether, this suggests that children as young as five can endogenously utilise cues to anticipate an upcoming event but only when they are encouraged to do so.

However, there is mixed evidence regarding the use of endogenous control in early-childhood in the AX-Continuous Performance (AX-CPT). Using Chevalier et al.'s (2015, 2020) definition of endogenous encouragement, this task 1) briefly presents the cue to make reactivation of this information more difficult and 2) manipulates the learned predictiveness of the cue. In this task, participants are sequentially presented with letter stimuli. They are informed to make a positive response if they see cue "A" followed by probe "X" and a negative response for derivative trials (AY, BX & BY). Similar to the Cued Visual Search task, manipulation of trial proportions (~70% AX trials) encourages participants to learn to expect probe "X" to appear after encoding cue "A" (Braver et al., 2009). Maintenance of cued information is demonstrated by greater difficulty (slower response times and poorer accuracy) on AY trials relative to BX trials. Previous research has demonstrated mixed findings for five- to six-year-olds by showing that endogenous cue-utilisation has either developed (Doebel et al., 2017; Gonthier, Zira, Colé & Blaye, 2019), not developed (Troller-Renfree, Buzzell & Fox, 2020) or is "in transition" (Lucenet & Blaye, 2014). Studies with older children have indicated that this skill has developed by age eight (Chatham, Frank & Munakata, 2009) but improves by age 11 (Lorsbach & Reimer, 2011). As such it is difficult to ascertain whether endogenous control has developed by early-childhood and whether this skill becomes adult-like by age 11 or if this is not attained until adolescence (Hämmerer, Li, Müller & Lindenberger, 2010; Iselin & DeCoster, 2009; Lorsbach & Reimer, 2008).

The Cued Visual Search task, which also fits the criteria for encouraging cue-maintenance, has shown that this skill has developed from age five and continues to improve through to mid-childhood. Research has shown that children aged five to six years old can utilise cues to guide their search towards a target based on their response time and saccadic movements (Brodeur & Boden, 2000; Jakobsen, Frick & Simpson, 2013; Landry, Johnson, Fleming, Crewther & Chouinard, 2019; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2002, 2005). This skill is suggested to become adult-like by age 10, as children of this age have demonstrated reliable endogenous cueing effects but these were significantly smaller than adults for when the cue is mostly predictive of the target's location (Amso & Scerif, 2015; Goldberg, Maurer & Lewis, 2001; Iarocci et al., 2009; Leclercq & Siéroff, 2013). They also show reduced anti-cueing effects (slower valid vs invalid) compared to adults, for when the cue is mostly unpredictive (i.e. cue informs where *not* to search) of the target's location in a search-display consisting of two locations (Leclercq & Siéroff, 2013). At the same time, 10-year-olds have been shown to recruit corresponding neural substrates to adults as both groups demonstrated enhanced posterior activity during cue encoding (but later and for longer periods in children), particularly in the high working memory capacity individuals (Shimi, Nobre & Scerif, 2015). This suggests that by mid-childhood, children's maintenance of task-goals to make facilitatory and inhibitory responses may have developed to ensure the use of endogenous control but this may be less robust relative to adults.

However, previous findings from the Cued Visual Search task raise a number of critical and unresolved issues. First, studies which showed children aged five to 11 have developed endogenous control assessed this by presenting children with an exogenous location cue which is known to produce a reflexive response (Brodeur & Enns, 1997; Brodeur & Boden, 2000; Leclercq & Siéroff, 2013; Pearson & Lane, 1990; Wainwright & Bryson, 2002, 2005). This research has all shown that five- to six-year-olds had larger cueing effects relative to older children. It was questioned whether this suggests younger children have an inhibition deficit leading to slower response times on invalidly cued trials (Brodeur & Boden, 2000). But it is also reasonable to suggest that larger cueing effects are a consequence of exogenous orienting in this age-group, which has been argued to be their default mode of control as they are considered to be less likely to use attentional resources at an early point in processing (Berger et al., 2005; Chevalier et al., 2015; Jonides, 1981). In support of this, five- to six-year-olds have showed large cueing effects for exogenous cues but weak cueing effects for endogenous cues (Johnson, Lewis & Cornish, 2020). Second, cueing effects in five- to six-year-olds has been shown to be less influenced by learned predictiveness of the cue (Brodeur &

Boden, 2000; Brodeur & Enns, 1997), whereas seven-year-olds have been shown to orient their attention only when the cue is mostly predictive of the target (Shimi et al., 2014). Indeed, longitudinal research has shown that endogenous orienting and inhibitory reorienting responses from invalid cues stabilises by age seven and continues to develop between eight and 10 years old (Lewis, Reeve & Johnson, 2016). Third, based on the above claims concerning the measurement of endogenous control in previous research, it is possible that this skill is underrepresented in nine- to 11-year-olds; making it difficult to make strong conclusions about the form of control acquired by this age-group. Therefore, it is uncertain at what age endogenous control has developed and how it compares to more experienced forms in mid-childhood.

In later life, research has suggested that endogenous control becomes impaired (Braver & Barch, 2002). Studies with the AX-CPT have shown that older adults experience greater difficulty (slower response times and poorer accuracy) on BX trials, relative to AY trials; suggestive of an impaired ability to maintain the early cue (Braver et al., 2009; Paxton, Barch, Racine & Braver, 2008). In support of this, older adults experienced difficulty maintaining the cue under conditions where there was a short cue-probe delay and even more so for long delay periods, when distracter letters impinged on processing (Harrmann, Ashling, Davelaar & Usher, 2005). This *goal-maintenance deficit* is argued to be a consequence of changes at the neural level in the prefrontal regions which impedes on the ability to maintain the contextual task-goal (Braver et al., 2009). Due to this, it is possible that there may be a qualitative shift back to the main use of exogenous control in older adulthood. Nevertheless, the depiction of the effect that aging has on cue-maintenance remains unclear. It is often understood that older adults have a task-goal maintenance deficit whereby they find it difficult to sustain a task-goal to guide their behaviour (Braver et al., 2009; Paxton et al., 2008). Contrary to this, in the AX-CPT evidence has shown that older adults behave endogenously which was exemplified at the behavioural level (Kray, Schmitt, Heintz & Blaye, 2015; Rush, Barch & Braver, 2006) and cortical level (Hämmerer et al., 2010). In correspondence with this, the influence of aging in the Cued Visual Search task was found to be lacking as cueing effects for both young and older adults were comparable (Humphrey & Kramer, 1997; Greenwood & Parasuraman, 2004; Madden, Whiting, Cabeza & Huettel, 2004). Thus, it is unclear whether aging impairs maintenance of a task-goal or whether this characteristic of endogenous control is preserved in seniority. Preservation of this skill may be due to compensatory mechanisms (Huang, Polk, Goh & Park, 2012) as in visual search, older adults have been shown to have enhanced prefrontal P3 activity during exogenous, and particularly in endogenous, search for the target (Li, Gratton, Fabiani & Knight, 2013). Therefore, it is uncertain whether aging leads to impairment or retainment of endogenous control at the behavioural level.

From the review of cue-utilisation research, there are a number of key points which require further investigation. The development of endogenous control has emphasised that there is mixed evidence concerning whether this skill is acquired by age five (Chevalier et al., 2015, 2020; Leclercq & Siéroff, 2013; Johnson et al., 2020) or later in childhood (Goldberg et al., 2001; Lorbach & Reimer, 2011; Shimi et al., 2014, 2015). In older adulthood, research suggests that maintenance of a task-goal based on context processing becomes impaired (Braver et al., 2009; Paxton et al., 2008), yet age-invariant effects have been found in Cued Visual Search and the AX-CPT (Kray et al., 2015; Greenwood & Parasuraman, 2004). Critically, evidence which found younger children and older adults are able to endogenously maintain cues in the Cued Visual Search task have mainly relied on using exogenous location cues to examine this higher-order skill. In addition to this, similar experimental paradigms which encourage cue-utilisation have found contrasting evidence to age-related findings in Cued Visual Search. In particular, the AX-CPT promotes cue-utilisation in a similar manner to Cued Visual Search by manipulating learned predictiveness at the block level (not a common variant in cued task-switching, except Chevalier et al., 2020), as well as brief presentation of the cue to form an expectancy about the upcoming probe or target. Therefore, it is of interest to consider whether cue-utilisation is a domain-general process by assessing if this skill is used similarly in different measures across age. Next, I will examine theories and empirical evidence regarding attentional capture before reviewing research on age-related changes in overcoming this process.

Attentional Capture

Attentional capture is often regarded as an unintentional process which can be caused from an item or event that is physically distinctive or shares features with our task-goals (Gaspelin & Luck, 2018). Such items or novel events are referred to in the literature as a *distraction* or something which causes an event to *pop-out*, such as the luminance change from a phone notification on a car dashboard. Research suggests that attentional capture is an automatic process in which attention is drawn towards an item or event within the first ~100ms it is presented in the visual field (Müller & Findlay, 1988). There is much debate concerning the cause of attentional capture and its involvement in attentional processing in everyday life (Folk, Remington & Johnston, 1992; Theeuwes, 2010; Treisman & Gelade, 1980; Wolfe et al., 1989). Top-down theories propose that it is the task-goal or *attentional set* which plays an active role in guiding attention towards items which share a task-relevant feature (Folk et al., 1992; Bacon & Egeth, 1994). Bottom-up theories of attentional capture suggest that it is the physical characteristics or the distinctiveness of a distracter item in our visual field which immediately guides attention towards it (Theeuwes, 1992; Theeuwes, 2010). Hybrid accounts, such as Guided Search (Wolfe et al., 1989; Wolfe, 2014) and the Signal Suppression hypothesis (Sawaki & Luck, 2010, 2013), describe the interaction between bottom-up and top-down processes in attentional capture. In this section, I will discuss the relevant theories of attentional capture which draw on the principles mentioned in our understanding of attentional selection, to portray how attention is guided towards a *salient* distracter and how this automatic response could be overcome.

Top-down theories of attentional capture stipulate that attentional selection is contingent on our task-goals (Folk et al., 1992; Bacon & Egeth, 1994; Lamy, Leber & Egeth, 2004). In many circumstances, a distracter item may share a target-defining feature which is maintained in our task-goal. For instance, the supermarket carpark may have an orange storefront and so the bright orange jacket of a construction worker may capture attention, as the colour feature is shared by the item we are intentionally searching for. In other cases, pre-knowledge and learned experience play a role in our formation of a task-goal which has been shown to contribute to top-down attentional capture (Anderson, Laurent & Yantis, 2011; Burra & Kerzel, 2013). Therefore, attentional capture is theorised to occur when a non-target item or distracter consists of a target-defining feature.

Evidence for this theory assesses whether the task-goal influences the occurrence of attentional capture (Folk & Remington, 1998). In the capture contingency paradigm participants are asked to search for a feature target (e.g. a red item) but to *ignore the unpredictive cues*. There are three types of cues: 1) compatible cue - includes a target-defining feature (e.g. a red cue), 2) incompatible cue – lacks a target-defining feature (e.g. a blue cue) and 3) irrelevant abrupt-onset (i.e. dynamic appearance and disappearance of an item which has been associated with a local change in luminance; Humphreys, 2016).

Research has shown that despite instructions to ignore the cue, adults tend to maintain and utilise compatible cues more than incompatible cues and irrelevant abrupt onsets, as they include a target-defining feature; this is often referred to as a *contingent capture effect* (Folk, Remington & Wright, 1994; Gaspelin et al., 2015; Lien, Ruthruff & Johnston, 2010; Yeh & Liao, 2008). A recent meta-analysis including 64 experimental studies of this paradigm showed reliable support for contingent capture effects in adults (Büsel, Voracek & Ansorge, 2018). Event Related Potentials (ERP) have also shown that adults produce an N2-posterior-contralateral (N2pc, indicator of attentional selectivity; Eimer, 1996) response in relation to compatible cues following 200 to 300ms after cue-onset, suggesting that selective processing of cues which matched a target-defining feature occurred prior to target selection (Lien, Ruthruff, Goodin & Remington, 2008). Despite instructions to ignore the unpredictive cue, when this item matched a feature of the maintained task-goal this led to attentional capture which suggests that capture is dependent on top-down processes.

In contrast to this, the main bottom-up theory of attentional capture posits that attention is guided towards the most salient item in our visual field or *attentional window* (Theeuwes, 1992; Theeuwes, 2010). They suggest than an item's or event's physical characteristics processed in the visual pathways make it distinctive. Bottom-up saliency is calculated by local feature contrast between an item and the surrounding items in a search-display (Desimone & Duncan, 1995). Importantly, bottom-up attentional capture is conducted at the preattentive level and is not subject to our task-goals. Rather, attention can be captured by a bright orange jacket of a construction worker despite our task-goal being to locate the supermarket carpark. In this instance, local feature contrasts are processed at the preattentive level and it is only after the most salient item in our visual field is selected do we then consciously identify this difference in feature values at the attentive level (e.g. bright orange jacket colour amongst grey carpark) (Theeuwes, 2010; Van der Stigchel et al., 2009). To disengage attention away from a salient distracter in this instance, top-down processing can be utilised at this late stage of processing to rapidly inhibit the distraction and serially search for the target (*rapid disengagement*; Theeuwes, 2010). This account draws on a "winner take all" depiction of bottom-up attentional selection as it is the feature computed to have the most physical salience which creates an attentional shift; this is a common mechanism described in both neural (Desimone & Duncan, 1995) and computational (Itti & Koch, 2001) models of bottom-up attention.

Supporting evidence for saliency accounts of attentional capture often use a variant of a the visual search task known as the additional singleton paradigm. Participants are presented with a search-display which includes a singleton target amongst non-target items (e.g. green *circle* target amongst green *diamond* non-targets). On a subset of trials, a singleton distracter which is more salient than the target (e.g. a red diamond) will be present in the display. If attention is guided towards the most salient item in the search-display, response times will be significantly slower on singleton-present trials relative to singleton-absent trials (Theeuwes, 2010). Research has found a range of attentional capture effects using this paradigm when the singleton distracter is defined by colour (Theeuwes, 1992; Gaspelin et al., 2017 – 51ms; Gaspar, Christie, Prime, Jolicoeur & McDonald, 2016 – 21ms) and orientation (Liesefeld, Liesefeld, Töllner & Müller, 2017 – 225ms). Saccadic and N2pc responses have been shown to be directed towards the singleton distracter before orienting towards the target (Gaspelin et al., 2017 – Experiment 1; Liesefeld et al., 2017). To enable search for the target, attention was first disengaged from the singleton distracter; this was represented by the late distracter positivity Pd ERP waveform (attentional suppression; Hickey, Di Lollo & McDonald, 2009). This evidence suggests that salience drives attentional selection at the bottom-up level and top-down control is instated at a late stage of processing to inhibit and rapidly reallocate attention away from the distraction.

Contrary to this, hybrid accounts of attentional capture suggest that this process can be overcome by instating an early task-goal (Sawaki & Luck, 2010, 2013; Wolfe et al., 1989; Wolfe, 2014). It is important to note that Guided Search (Wolfe et al., 1989; Wolfe, 2014) suggests attentional selection is first encoded by bottom-up processing of feature maps but that top-down attentional weights given to certain feature values can heighten the saliency computation for that element in the master feature map to volitionally guide attention. The Signal Suppression hypothesis expands and applies this understanding to attentional capture by suggesting all visual stimuli produce an early “attend to me” signal based on bottom-up saliency computations. Importantly, this early signal can be suppressed if participants maintain an early task-goal (Sawaki & Luck, 2010). Absence of a robust task-goal to guide search has been theorised and evidenced empirically to lead to attentional deployment towards the singleton distracter (Sawaki & Luck, 2013). Further supporting evidence comes from variants of the additional singleton paradigm, which are often used to provide evidence for bottom-up theories of attentional capture. Much of the research conducted with this paradigm has asked participants to search for a singleton target whilst also asking them to ignore a singleton distracter (Liesefeld et al., 2017; Theeuwes, 1992). This may be encouraging participants to utilise a singleton detection mode where they search for the “odd” item or the discrepancy in the search-display rather than actively searching for the instructed feature (e.g. a circle; Bacon & Egeth, 1994; Eimer & Kiss, 2008). By changing the appearance of the non-targets from a homogenous (e.g. all diamonds) to a heterogenous (e.g. diamonds, hexagons and squares) display, studies which previously reported attentional capture effects showed this to be lacking for the same singleton distracter (Bacon & Egeth, 1994; Gaspelin et al., 2015, 2017; Jannati, Gaspar & McDonald, 2013). Pd responses related to the singleton distracter have been shown to occur before deploying a target-N2pc, but importantly here, no distracter-N2pc was found which suggests that the singleton distracter was suppressed before it captured attention (Jannati et al., 2013; Gaspelin & Luck, 2018). Therefore, Guided Search and the Signal Suppression hypothesis can explain the disparities in attentional capture research as they suggest that a bottom-up response can be overridden if an early top-down goal is present to inhibit this saliency signal before it is consciously attended to.

The concepts described in this section highlight the debate concerning the cause of attentional capture as well as the types of strategies which can be used to overcome this process. From the review of the aforementioned empirical findings and our knowledge of attentional selection, it is possible that maintenance of an early task-goal can inhibit further processing of a bottom-up signal (Gaspelin et al., 2015, 2017; Sawaki & Luck, 2010, 2013; Wolfe, 2014). Much of the research considering distraction in children have used a qualitative approach to assess this (Erickson et al., 2015; Fisher et al., 2014; Godwin & Fisher, 2011; Rodrigues & Pandeirada, 2018). I will now consider the influence of age on attentional capture and pay specific attention to the relationship between endogenous cueing and distraction in this literature.

Attentional Capture: Developmental & Aging Effects

There is a limited amount of research which has specifically investigated attentional capture effects in children. Research which has used observational methods to understand children's attention, has shown that bright classroom displays impinge on recall of learnt material in children aged five to 12 years (Erickson et al., 2015; Fisher et al., 2014; Godwin & Fisher, 2011; Rodrigues & Pandeirada, 2018). Capture continency paradigms have demonstrated that, unlike adults, children aged four to five were distracted by unpredictive cues irrespective of whether it was compatible with a target-defining feature (Gaspelin et al., 2015). This suggests that children aged four to five years old are more reliant on an exogenous strategy and so they are prone to attentional capture from distractions. In contrast, there is mixed evidence concerning whether children aged nine to 11 are able to overcome attentional capture using endogenous control in a standard visual search task (Wong-Kee-You, Tsotsos & Adler, 2019; Michael, Lété & Ducrot, 2013).

Similarly, in older adulthood attentional capture effects have been studied using different experimental paradigms which makes it difficult to draw comparisons. Some research argues that aging is related to an inhibition deficit (Salthouse, Atkinson & Berish, 2003; West, 2000). In a delayed recognition task, older adults were better at recalling a face that they were instructed to ignore which was related to reduced suppression (N170; face-sensory waveform) for this item (Clapp & Gazzaley, 2012; Zanto, Hennigan, Ostberg, Clapp & Gazzaley, 2010). Capture contingency effects were found for both young and older adults but capture by incompatible cues, which did *not* consist of a target-defining feature, was greater in older adults (Pratt & Bellamo, 1999). This suggests that older adults are more prone to bottom-up distraction. In contrast to this, others argue that inhibition of attentional capture is preserved in old age (Madden, 2007). Specifically, older adults were as effective as young adults in inhibiting a colour singleton distracter in a visual search task (Costello, Madden, Shepler, Mitroff & Leber, 2010). Age-invariant effects have also been found for inhibiting an irrelevant abrupt-onset (local luminance change), as response times and saccadic latencies were similar between age-groups but older adults made more fixations (Kramer, Hahn, Irwin & Theeuwes, 1999; Lien, Gemperle & Ruthruff, 2011). Much of the research with this age-group induced an early task-goal using a variety of experimental manipulations (i.e. explicit vs implicit instructions) or defined and measured attentional capture differently (i.e. top-down vs bottom-up capture), which makes it difficult to ascertain the conditions required for older adults to inhibit capture effectively.

In a variant of the Cued Visual Search task, endogenous and exogenous processes were compared and competed for attention in a lifespan study (Iarocci et al., 2009). Participants were provided with an endogenous arrow cue which was immediately followed by the brief presentation of an unpredictive exogenous location cue before the search-display appeared. If the reflexive response to the location cue could be suppressed, then cueing effects were expected to be modulated by endogenous cues in guiding search when attention was in competition (i.e. endogenous cue was valid, but exogenous cue was invalid). The findings showed that children and adults were captured by the location cue, but nine-year-old's and young adults were able to modulate and recover from this better than six-year-olds and older adults. In support of this, an endogenous arrow cue was unable to overcome an exogenous location cue in young and older adults, but young adults were better at modulating this reflexive response (Juola, Koshino, Warner, McMickell & Peterson, 2000). Research using this variant of the Cued Visual Search task suggests that endogenous cue-utilisation is unable to override a reflexive response to a brief and irrelevant location cue across the lifespan. Age differences occurred in the ability to rapidly recover from capture, which was poorer in younger children and older adults.

However, it is questionable whether the assessment of attentional capture using the aforementioned variant of the Cued Visual Search task is a valid measure of endogenous orienting. Across age, it is known that endogenous cue-utilisation is found using stimulus onset asynchronies (SOAs) above 200-300ms, with longer SOAs allowing participants to have more time to prepare and anticipate the upcoming cued location or feature (Berger et al., 2005; Jonides, 1981; Wainwright & Bryson, 2005). If maintenance of an endogenous cue is disrupted during the cue-target interval, this can lead to reduced cueing effects (Soto et al., 2008). Indeed, seven-year-olds benefited less from location cues presented during maintenance of a to-be-recalled memory array relative to early arrow cues (Shimi et al., 2014). As such it is possible that endogenous cue-maintenance is interrupted by the brief presentation of an exogenous cue and so attentional control is more likely to switch to an exogenous form of control. Moreover, as I discussed earlier, saliency computations are argued to be calculated by comparing bottom-up and top-down weights assigned to features in a search-display and the feature with the most activation in the master map, creates an attentional shift (Desimone & Duncan, 1995; Theeuwes, 2010; Wolfe et al., 1989; Wolfe, 2014). By presenting the salient distracter and the target in the same search-display, rather than separate sequential displays, we can put both of these items in direct competition with one another (Theeuwes, 2010; Van der Stigchel et al., 2009). If an endogenous cue signals a feature of the target, this can inform us about whether this process can bias attentional resources towards the target when at the same time, a salient distracter is also competing for attention. Therefore, the influence of endogenous cues on attentional capture warrants further investigation to understand the dynamic between top-down and bottom-up signals on attention. In the next section, I will review the existing research on endogenous cue-utilisation and distraction before highlighting the aims of my thesis.

Endogenous Cue-Utilisation & Attentional Capture

There are a limited number of studies which meet the criteria mentioned above for assessing endogenous cue-utilisation and attentional capture in the Cued Visual Search (for a review, see Chelazzi, Marini, Pascucci & Turatto, 2019). Yet there are still some unresolved issues in this literature. Studies which cued attention towards the target have shown that endogenous control can reduce, but not prevent, attentional capture. For example, Theeuwes and van der Burg (2008, 2011) presented adults with a mostly predictive (80% valid) shape or colour cue to guide search towards the target. On some of the trials, participants were presented with a colour singleton distracter (i.e. a red item amongst green items). They found that response times were significantly faster on valid trials relative to neutral trials, when the singleton distracter was present in the search-display. This suggests that participants were able to utilise endogenous cues to orient their attention towards the target and reduce capture by the singleton distracter. However, the authors argued that the central cues did not encourage endogenous control but rather *primed* attention exogenously and the reduced capture may be a result of intertrial effects. This speculation was based on the findings from their previous study which used this task, whereby significant cueing effects were found for both predictive (80% valid) and unpredictive (20% valid) block conditions; suggesting participants utilised the cue regardless of its predictiveness (Theeuwes, Reiman & Mortier, 2006). Granted, cueing the featural colour of the target has been shown to have exogenous cueing effects in unpredictive block conditions, much like shape cues (Soto & Humphreys, 2007), conversely cueing effects are significantly greater in predictive block conditions (Kasten & Navon, 2008; Laarni, 2001). As the research from Theeuwes and colleagues (2006, 2008, 2011) did not compare predictive and unpredictive cueing effects, it remains uncertain whether their conclusions concerning endogenous control and capture hold validity.

Some evidence has shown that cueing a feature of the distracter can increase suppression for this item, with better suppression found for when the target feature was cued (Arita, Carlisle & Woodman, 2012). However this study did not include a salient or singleton distracter to assess the role of endogenous cue-utilisation on attentional capture. Others which investigated attentional capture questioned whether prior knowledge concerning the salient distracter would lead participants to acquire a top-down rejection template to inhibit this expected distracter location or feature at an early point in processing (Beck, Luck & Hollingworth, 2018; Moher & Egeth, 2012; Wang & Theeuwes, 2018). It was shown that cueing the salient distracter's location or feature did not prevent or reduce attentional capture. Saccadic responses showed attention was initially captured by the cued salient distracter, before avoiding this item when searching for the target (Beck et al., 2018; Moher & Egeth, 2012). It has been suggested that cueing the feature or location of the salient distracter will encourage participants to maintain this information in working memory to guide attention towards this cued item rather than away from it (Chelazzi et al., 2019). Nevertheless, based on our understanding of hybrid accounts of attentional selection and capture (Wolfe et al., 1989; Wolfe, 2014; Sawaki & Luck, 2010, 2013), enhancing the signal attributed to the target is argued to facilitate search for this item and lead to reduced attentional shifts towards task-irrelevant items. Importantly, the results and conclusions from the research thus far, warrant further investigation in adults and I also plan to extend this assessment to children and older adults, to ascertain whether endogenous cue-utilisation influences attentional capture across the lifespan.

Much of the supporting evidence for the influence of endogenous control on attentional capture have induced an early task-goal via explicit instructions (i.e. search for the circle target) or by manipulating the heterogeneity of the non-target items (i.e. circle target amongst, square and hexagon non-targets) (Bacon & Egeth, 1994; Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017; Hickey et al., 2009; Jannati et al., 2013). Despite the knowledge that endogenous cues can guide search at an early point in processing, it is still uncertain 1) whether this skill can reduce attentional capture and 2) how age influences this relationship.

Thesis Aims

From the review of research, this chapter has highlighted the relevant limitations and gaps in both endogenous control and attentional capture fields. Specifically, the interaction between endogenous and exogenous processes has been questioned and requires further assessment. This thesis aimed to understand the following themes:

1. **Endogenous Cue-Utilisation** – I tracked the developmental trajectory of this skill by making age-related comparisons and I assess the conditions required to encourage this strategy in measures of endogenous control.
2. **Attentional Capture** – I questioned the limits of endogenous cue-utilisation by investigating whether this higher-order skill can reduce or prevent a salient distraction in children and adults.
3. **Maintenance & Inhibition Relationship** – the ability to maintain an early cue has been emphasised as to play a key role in the inhibition of a salient distracter. Therefore, I examined if these processes are related to one another across the lifespan.

In this thesis I begin by explaining the developmental trajectory of the skills highlighted above from childhood (5-11 years) to young adulthood, before moving on to examine age-related changes in older adulthood and methodological factors in young adulthood.

In **Chapter 2**, I used the additional singleton paradigm to create and test whether a singleton distracter produced reliable attentional capture effects in young adults. This validated my use of this salient distracter in Chapters 3, 6 and 7. In **Chapter 3**, I assessed the development of endogenous cue-utilisation and its relationship with attentional capture in children and young adults using a modified version of the Cued Visual Search task. **Chapter 4** conducted further analyses using data from Chapter 3 to explore the presence and influence of colour priming effects on my baseline measure of cue-utilisation. **Chapter 5** examined the influence of block predictiveness on cue-utilisation in early- and mid-childhood to understand the role of task monitoring in this paradigm. In **Chapter 6**, I investigated age-related changes in cue-utilisation and attentional capture with young and older adults using the Cued Visual Search and the AX-CPT; this questioned whether endogenous cue-utilisation is a domain-general or domain-specific skill. **Chapter 7** considered the role of task difficulty by manipulating search for a featural (i.e. one feature) or conjunctive target (i.e. two features) to understand whether increasing cue-utilisation demands impacts attentional capture in young adults. Finally, **Chapter 8** discussed the findings from the previous chapters and used a developmental approach to make insights into the mechanisms involved in the dynamic between attentional selection and attentional capture processes.

Chapter 2: Attentional Capture of a Shape Singleton Distracter in the Additional Singleton Paradigm

Abstract

In Chapter 1, I highlighted the relevant accounts of attentional selection and attentional capture which helped us to understand how attention can be guided by physical features and task-goals. Attentional capture is often understood as an automatic and involuntary process which guides attentional resources towards an item or event in our visual field. Much of the current literature has used a colour singleton in the additional singleton paradigm to create capture effects (slower on singleton-present vs singleton-absent trials). This chapter aims to validate and assess whether a shape singleton presented amongst different coloured circles creates capture effects. This study invited young adults (N = 15) to search for a white tilted line target in the additional singleton paradigm (variant of the standard visual search task). The target line was presented within one of three coloured circles and, importantly, a shape singleton distracter was presented on 41.67% of trials. The results showed a moderate capture effect, in that the presence of the shape singleton distracter slowed response times by 41ms relative to its absence from the search-display. It was also shown that the location of the shape singleton distracter in relation to the target influenced accuracy, as when this item was positioned closer to the target this led to greater accuracy relative to when it was further away (no location effect found for response times). In this chapter, I discuss the findings in the context of attentional capture accounts and highlight the future directions for these results.

Introduction

Given our understanding of the processes involved in attentional capture and its subsequent inhibition, I aim to consider the role of the salient distracter in the current research. Specifically, in the current chapter I aim produce an item which can guide attention via attentional capture. I plan to use this item in future studies in this thesis to assess whether the capture effects, caused by this distracter, can be reduced or prevented by an endogenous colour cue. To help me to create this item, it is first important to consider the factors which can enhance (and reduce) capture. I will review the attentional capture literature to consider bottom-up saliency computations, heterogeneity of non-target items as well as the distance between the salient distracter and the target. This will assist me in the design of this item, as well as allow me to examine the influence of distracter-target distance on search to inform future studies.

The relationship between the defining feature (e.g. colour, shape) of the target and the distracter is argued to play a vital role in attentional capture (Bundesen, 1990; Found & Müller, 1996). More specifically, when the distracter is a *singleton* this means that it has a unique feature value in a dimension (Van der Stigchel et al., 2009). For example, a black circle amongst green circles (colour singleton) or a diamond amongst circles (shape singleton). A singleton defined in this way is argued to be resistant to perceptual grouping, as it has a unique feature value that is different from the surrounding local features (Humphreys, 2016; Humphreys & Müller, 1993). Research has shown that when the distracter is a singleton in a different dimension to the target, this can lead to reliable attentional capture for this item (red circle singleton distracter, green diamond target & green circle non-targets; Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017; Jannati et al., 2013; Theeuwes & van der Burg, 2008). Bottom-up and hybrid accounts of attentional capture suggest that saliency is computed by comparing bottom-up signals for a feature relative to the surrounding features in the array (Desimone & Duncan, 1995; Theeuwes, 2010; Wolfe et al., 1989; Wolfe, 2014). Therefore, saliency activations for a unique feature value in a different dimension to the target would be enhanced in the master map, leading to an attentional shift towards this item.

Much of the attentional capture research has focused on shifts in attention for disparities between different dimensions, but disparities within a dimension (such as orientation) can also cause significant capture (Yen & Finkel, 1998). Evidence has shown that participants initially deployed attention (N2pc) towards the singleton distracter (45° line), followed by the singleton target (12° line) which was presented amongst vertical non-target lines (Liesefeld et al., 2017). This suggests that disparities within the orientation dimension can produce large capture effects as this singleton distracter slowed response times by 225ms when it was present, relative to absent, in the display. Indeed, others have found that search for a singleton target benefited from closed contours or edges, as opposed to open contours (Kovács & Julesz, 1993, 1994). Blurring of edges has reliably been shown to reduce saliency and capture for local items, relative to high contrast edges which increased saliency and capture effects (Mevorach, Humphreys, Shalev, 2005, 2009; Tsvetanov, Mevorach, Allen & Humphreys, 2013). This suggests that disparities in feature values within a dimension, such as those shown for orientation and edges, can guide attention in a bottom-up manner.

In addition to the points highlighted above, the appearance of the non-target items are argued to play a vital role in saliency computations (for a review, see Humphreys, 2016). In attentional capture research, the singleton distracter is manipulated so that it is more salient than the target (Mevorach et al., 2010). The most common way to enable this is by presenting an homogenous display of non-target items which share a feature of the target. For instance, in the additional singleton paradigm, participants are presented with a green diamond target, green circle non-targets and a red circle distracter (Theeuwes, 1992; Gaspelin et al., 2015, 2017). Here, perceptual grouping of green features will reduce the saliency activation for the target relative to the red singleton distracter (Humphreys, 2016). That being said, you would also expect perceptual grouping of circle features to reduce the saliency of the red circle distracter but this has not been found (Theeuwes, 1991, 1992) but I will discuss this in further detail in the Discussion. Coming back to my earlier point, some would argue that preattentive perceptual grouping of colour can lead to suppression of green; reducing the target-signal and allowing attention to be engaged by the most salient item in the search-display (Bundesen, 1990; Found & Müller, 1996; Humphreys & Müller, 1993). In general, the saliency relationship between the target and distracter can be modulated by the appearance of the non-targets; with homogenous non-targets leading to greater attentional capture effects.

However, it is argued that attentional capture effects in the additional singleton paradigm are a result of a search strategy being employed rather than differences in bottom-up saliency computations (Bacon & Egeth, 1994). Evidence has shown that by defining the target as a singleton in this paradigm (i.e. green diamond), this encourages a singleton detection mode whereby participants rely on searching for the “odd” item in the display and so a red singleton distracter is likely to capture attention (Bacon & Egeth, 1994; Eimer & Kiss, 2008; Lamy, Leber & Egeth, 2004). Indeed, capture effects for the same singleton distracter have been shown to disappear when it is presented in a heterogenous display of non-targets; encouraging top-down search for a specific feature (feature search; Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017). It is therefore questionable whether an attentional capture effect can be found for a singleton distracter in a heterogenous display of non-targets where perceptual grouping of these items is made more difficult.

Importantly, an overarching factor which can influence attentional capture is the distance between the target and the singleton distracter. Bottom-up (Theeuwes, 2004; Theeuwes, 2010) and a hybrid account of attentional capture (Desimone & Duncan, 1995) posit that if the target and the singleton distracter are in the same *attentional window* or receptive field, attentional resources will shift towards the most salient feature within this window. In particular, if the attentional window encompasses the whole search-display, then capture from a singleton distracter is predicted to occur (with no support from top-down processes), whereas serial search is said to reduce the size of this window as items are being reviewed in small clusters and so in this case, capture is less likely to occur (Van der Stigchel et al., 2009). Evidence has manipulated the size of the attentional window by encouraging participants to learn to serially search for the target (i.e. when they saw fixation was a circle), but to search across the entire display when the items were shaped in an upward triangular array (Belopolsky, Zwaan, Theeuwes & Kramer, 2007). They showed no capture in serial search for smaller attentional windows but capture effects when instructions promoted search across the search-display. Others have shown that when search for the target is easy (low perceptual load) this can promote a large window and lead to capture, relative to difficult search trials (high perceptual load) where there are less available attentional resources to spill over to distracters (Theeuwes, Kramer & Belopolsky, 2004). In situations where the target and the singleton distracter are located close to one another, the singleton distracter is most likely to fall within the same attentional window of the target, presumably in serial search for the target as well. Therefore, the singleton distracter could essentially act as an exogenous cue to guide a reflexive shift in attention towards the target location when it is positioned close to this item. As a result, attentional capture could benefit search for the target when the singleton distracter is located nearby.

In contrast to this, distance effects are argued to worsen search for the target. The *spatial surround suppression* hypothesis proposes that items that are immediately surrounding our focus of attention can be suppressed (Sundberg, Mitchell & Reynolds, 2009; Tsotsos, 1995). In behavioural and oculomotor studies, attentional capture effects were indeed larger when the singleton distracter was positioned close to the target, but response times and saccadic latencies to the target were slower on these trials (Gaspar & McDonald, 2014; Gaspelin et al., 2017; Mounts, 2000). Other research has shown that neural responses to a dot probe were significantly reduced when it was closely located to a singleton target that attracted attention (Hopf et al., 2006). But when the dot probe was *within* the focal ring of attention with the target, neural responses were enhanced for this item. This suggests that when attention has been deployed and focused on an item (e.g. singleton distracter), surrounding items (e.g. adjacent target) are more likely to be inhibited and therefore slowing search for this item. But it further stipulates, in agreement with the attentional window hypothesis, that if the target is within the focal of attention then search for the target will be improved.

From this review of methodological factors in attentional capture research, it is highlighted that an item which has a unique feature value and closed contour edges which make it distinctive from the surrounding items, can create capture at the bottom-up level; this helped me to create my singleton distracter. It is also important to understand the relationship between the target and the distracter item with regards to their dimension, distance as well as their association with non-target items in the display. Much of the research in attentional capture so far have used a colour singleton distracter and many in the literature have often questioned whether other featural singleton items can produce capture in different search-displays (see Gaspelin et al., 2017; Liesefeld, Liesefeld, Pollmann & Müller, 2018). Next, I will describe the salient distracter I have chosen to investigate and explain my reasoning based on the factors highlighted.

The Current Study

I plan to design a search-display which can be incorporated into a Cued Visual Search task that uses endogenous colour cues to guide search towards an item in the display. This study aims to assess whether a salient distracter can produce attentional capture effects and whether the location of this item influences search for the target. Using the additional singleton paradigm, participants will be displayed with three circles in different colours which contain either a vertical or the tilted line target. They will be asked to search for the tilted line and make a discriminatory judgement with regard to the direction of its tilt (L/R). On some of the trials (41.67%), an irrelevant salient distracter item will be present in the search-display. I chose a black diamond singleton distracter to be presented amongst the differently coloured circle items in the display. This item meets the criteria for causing attentional capture. First, it is a singleton diamond shape amongst circle items and so this unique feature value within the shape dimension, is likely to produce larger activations in the master map and less likely to be perceptually grouped relative to the homogenous circle items in the display (Humphreys, 2016; Liesefeld et al., 2017; Theeuwes, 2010; Wolfe et al., 1989; Wolfe, 2014). That being said, the singleton distracter and the circle items in the display (one of which includes the target) are all different colours and so they all have different feature values in the colour dimension. Second, the diamond singleton distracter will have closed contour edges which increases it saliency compared to the coloured circles which will have blurred edges (Kovács & Julesz, 1993, 1994; Mevorach et al., 2005, 2009; Tsvetanov et al., 2013). To note, the singleton distracter will not replace a non-target circle item in the search-display, as often done in previous studies using the additional singleton paradigm (*see Method|Design for further information*). I will assess whether the distance between the target and the singleton distracter influences attentional capture and search for the target.

This investigation will add to the current attentional capture literature as it is less known whether a shape singleton distracter will lead to capture when it is present amongst a heterogenous display of colourful items. This study will be conducted with young adults, with the assumption that attentional capture effects for a singleton distracter found in adults will create larger capture in children as their ability to inhibit distracting information is still developing (Diamond, 2013; Gaspelin et al., 2015; Iarocci et al., 2009; Wong-Kee-You et al., 2019). If attentional capture is found, participants are expected to perform worse (slower response times and poorer accuracy) on singleton-present trials, relative to singleton-absent trials. In addition, it is predicted that closer distances between the target and the singleton distracter will benefit performance (faster response times, better accuracy) relative to far distances, supporting attentional window theories (Theeuwes, 2004, 2010). If closer distances leads to worse performance (slower response times, poorer accuracy) this would support spatial surround suppression theories (Tsotsos, 1995).

Method

Participants

15 typically-developing adults (*M* = 23.67, *SD* = 1.51; range = 20.92 – 25.92 years and months; 13 female, 2 male) were recruited for this study[1]. All participants were postgraduate students from the University of Nottingham. All participants were right-handed and reported to have normal or corrected-to-normal vision, no formal diagnosis of colour blindness or developmental differences, specifically Autistic Spectrum Disorder and/or Attention Deficit and Hyperactivity Disorder[2]. All participants provided informed consent to take part in the study and were provided with a £2 inconvenience allowance. This study had full ethical approval from the University of Nottingham School of Psychology Ethics Committee.

Design

A within-subjects design was used which had two independent variables. The presence of the singleton distracter (2 levels: singleton-absent, singleton-present) was manipulated to assess whether the presence of this item on 41.67% of trials impinged on performance relative to its absence from the search-display. The actions taken to counterbalance the items in the search-display meant that on 8.33% of trials (24 out of 288 trials), the singleton distracter was presented in the same quadrant of the screen as the target (*see Figure 2.1 for counterbalancing measures*). I assessed whether the location of the singleton distracter (2 levels: same-quadrant, different-quadrant to the target)[3] influenced performance.

The search-display used in the current study differs from previous research which has used the additional singleton paradigm. Past research usually replaces one of the non-target items in the search-display as the

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[1] A power analysis was not conducted for this study prior to data collection. The sample size was based on previous research which has used shape and colour in an additional singleton paradigm, who had sample sizes ranging from 10 to 20 participants (Gaspelin et al., 2015, 2017; Theeuwes, 1992; Theeuwes et al., 2006).

[2] Ethnicity data was not recorded for this sample.

[3] Near-distance trials will now be referred to as same-quadrant trials and close-distance trials as different-quadrant trials.

Step 1 Coloured Circles

Each of the four colours equally presented in each quadrant of the search-display.

Participants could not learn that a particular colour (e.g. pink) appears in one location (e.g. upper-right corner) more than others.

Step 2 (Target line)

Equally likely to be presented in any of the 4 colours and any of the 4 quadrants.

The colour of the circle which included the target line and its location in the search-display, were equally likely to have a left or right tilted target.

Participants could not learn target line is in one colour and location more often than others.

Step 3 (Singleton distracter)

Equally likely to be presented in any of the 4 quadrants.

The same quadrant shared by any of the four coloured circles or in a quadrant occupied by no colours.

This counterbalancing meant that the singleton distracter was presented in the same quadrant as the target on 8.33% of trials (12 trials) per block condition. The impact of this was mitigated by making sure each colour and quadrant associated with the target line represented three of these types of trials each.

Participants could not learn black diamond distracter usually appears in one location (e.g. upper-right corner) or that it usually appears next to a particular colour (e.g. pink circle).

Figure 2.1. Schematic representation of the steps involved in counterbalancing the colours, target and singleton distracter items in the search-display.

singleton distracter (e.g. green circle non-target is replaced by red circle singleton distracter; Theeuwes, 1992; Bacon & Egeth, 1994; Gaspelin et al., 2017). In the current study, I did not replace one of the non-target circles but rather presented the singleton distracter as an additional item in the search-display. This method was chosen as I prioritised the counterbalancing of colour, location and their interaction with the target and singleton distracter. It was not possible to replace a non-target with a singleton distracter (e.g. blue circle replaced with diamond), as this would have led to learned associations between colour and the singleton distracter. Statistical learning for location and featural information has been shown to be a strong factor for cueing attention, as well as for encouraging attentional capture effects (Anderson et al., 2011; Wang, van Driel, Ort & Theeuwes, 2019). Learning of the location or feature information can also reduce attentional capture effects, as early anticipation can lead to suppression (Munneke, Heslenfeld, Usrey, Theeuwes & Mangun, 2011; Serences, Yantis, Culberson & Awh, 2004). As the search-display used in this chapter would be incorporated in a Cued Visual Search task in future chapters, this meant that there were multiple layers with regard to the target, cue and singleton distracter which needed to be controlled.

Stimuli

Participants were first presented with a fixation cross (0.41° width x 0.41° height) presented in black Arial font on a white background for 500ms. Next, the search-display was presented until participants made a response (*see Figure 2.2 overleaf*). The search-display consisted of a fixation cross and three coloured circles (each 4.90° width x 4.90° height). All four colours were equally presented in each quadrant of the screen (pink [X= 67.96, Y=54.41, Z=60.99], yellow [X = 80.49, Y = 78.77, Z = 34.52], blue [X = 58.15, Y = 65.95, Z = 87.82] and green [X = 57.87, Y = 83.53, Z = 50.62 cd/m^2]; CIE XYZ 1931 Colour Space; Smith & Guild, 1931). These colours were chosen on the basis that they are considered as being categorically distinct colours in western societies (Franklin, Pilling & Davies, 2005). The circles were created using

GIMP software (The GIMP Development Team, 2019) and had a raised cosine mask applied to them to form a blurred circular outline (0.59° fringe width). Each circle was presented in one of four quadrants of the screen, leaving one quadrant blank on each trial. On each trial, each circle was presented in one of four randomly selected locations within each quadrant (ranging between 4.09° to 4.90° away from fixation on *x* and *y* axis respectively). This ensured the locations of the circles varied across trials. On each trial, two coloured circles contained a white vertical line (0.08° width x 0.41° height) in their centre and the remaining circle contained the white tilted line target which was presented with equal probability either 45° clockwise or anticlockwise from vertical for all colours and quadrants in each block condition. The singleton distracter was a black diamond (1.55° width x 1.55° height; black [X = 4.29, Y = 4.38, Z = 4.52 cd/m^2]) which was presented on 41.67% of trials. The singleton distracter was presented in one of four randomly selected locations within each quadrant (locations ranging between 0.82° and 2.45° away from fixation on *x* and *y* axis respectively). There was no overlap between the circles and the singleton distracter.

Apparatus & Materials

A iiyama ProLite GB2488HSU monitor (39.64° width x 32.74° height) was used to display the stimuli. The stimuli were mirrored from an Apple MacBook Pro 2 Laptop via a HDMI 2.0 cable. Both devices used a frame rate of 60Hz per/frame. An Apple keyboard was connected to the Apple MacBook Pro 2 via USB, to record participants' responses. The experiment was run using PsychoPy 2 v1.85 (Peirce, 2008), which was also used to create the line, fixation and singleton distracter stimuli.

Procedure

All participants were seated 70cm away from the monitor in a darkened, noise- controlled lab. They were instructed that they were about to take part in a visual search task, involving finding a target amongst coloured circles. They were instructed to find the white tilted-line target as fast

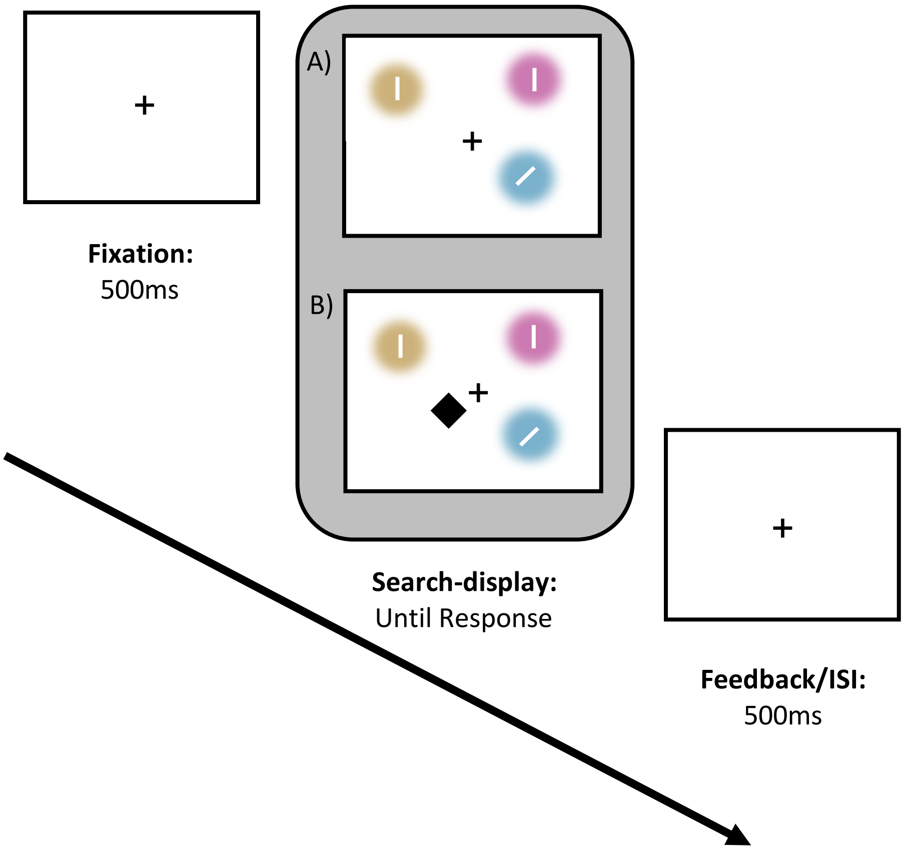

Figure 2.2. Schematic representation of the sequential order of the additional singleton paradigm with time durations. Following fixation, the Search-display was either a singleton-absent (A) or a singleton-present (B) trial. Participants responded to the tilt (L/R) of the tilted white line target (represented in the blue circle).

and accurately as they could. They were made aware that on some trials they would see a black diamond but were reassured that their task was to focus on finding the tilted-line target. The instructions read: “*sometimes you’ll see a black diamond on the screen and sometimes you won’t, but that’s ok because your task is just to find the white tilted line target*”. No further instructions about the singleton distracter were provided. The participants were instructed to press the “z” key if the target was tilting towards the left and the “/” key if it was tilting towards the right. Stickers were placed on top the “z” and the “/” keys to help with finger placement.

Participants received 16 practice trials to familiarise them with the buttons and task. Of the practice trials, 5 trials contained the singleton distracter. If participants made three or more inaccurate responses, the practice phase was repeated. No participants repeated the practice phase. Feedback for inaccurate responses was provided on both practice and experimental trials, which read "Oops! Wrong way!" in red Arial font (0.41° width x 0.41° height) in the centre of the screen for 500ms. No feedback was provided for accurate responses, instead a fixation cross was presented during the interstimulus interval (ISI).

All participants completed 288 trials which included two break periods. Of the 288 trials, 120 trials (41.67%) included the singleton distracter. 24 of these trials (8.33%) displayed the singleton distracter in the same quadrant as the target. Following completion, the participants were debriefed and were provided with £2 inconvenience allowance. The experiment took approximately 15-20 minutes to complete.

Results

Data Processing

Outliers were filtered by excluding data where response times were +/-4SD away from a participant's median response time (0.58% data removal). The first trial and the first trial following a break period (two break periods were provided) were removed from the analyses (0.91% data removal). Inaccurate trials were removed from the analysis of response times. Mahalanobis distance for each participant from the chi-squared distribution of the sample was calculated based on response time and accuracy across singleton-presence and singleton location conditions. No multivariate outlying participants were found (p > .001).

This study had two aims which was to assess attentional capture by comparing behavioural performance on singleton-present relative to singleton-absent trials. I also aimed to understand whether the location of the singleton distracter in relation to the target's location, influenced performance. For this latter aim, I needed to analyse whether singleton location (2 levels: same-quadrant, different-quadrant from the target) interacts with singleton presence (2 levels: singleton-absent, singleton-present). If the singleton location affects performance, this is expected to influence performance on singleton-present trials only. Inclusion of singleton-absent trials within this analysis will allow us to encompass a suitable baseline measure for understanding this effect. Dummy variables were assigned to singleton-absent trials by labelling them as "same-quadrant" and "different-quadrant". This was conducted using the RAND() function in Microsoft Excel on singleton-absent trials and these values were organised from smallest to largest. The first half of random values were assigned "same-quadrant" labels (1256 trials) and the latter half were assigned "different-quadrant" (1256 trials).

Separate 2 (Singleton Presence) x 2 (Singleton Location) within-subject ANOVAs were conducted on median response times (in seconds) and mean accuracy data. All simple main effects analysis had Bonferroni correction applied. An alpha criterion of .05 was used as the significance level. In the current chapter and throughout this thesis, between-subject confidence intervals for an individual mean are reported (Pfister & Janczyk, 2013).

Response Time

A main effect of Singleton Presence was found ($F(1, 14) = 29.96$, $p < .001$, $\eta_p^2 = .68$). This showed that response times were significantly slower by 41ms on singleton-present, compared to singleton-absent trials. A main effect of Singleton Location was not significant ($F(1, 14) = 2.19$, $p = .161$, $\eta_p^2 = .14$; same-quadrant: M = .72, SE = .03 [95% CI .66, .78]; different-quadrant: M = .73, SE = .03 [95% CI .67, .79]). No Singleton Presence x Singleton Location interaction was found ($F(1, 14) = 1.54$, $p = .235$, $\eta_p^2 = .10$; *see Figure 2.2*).

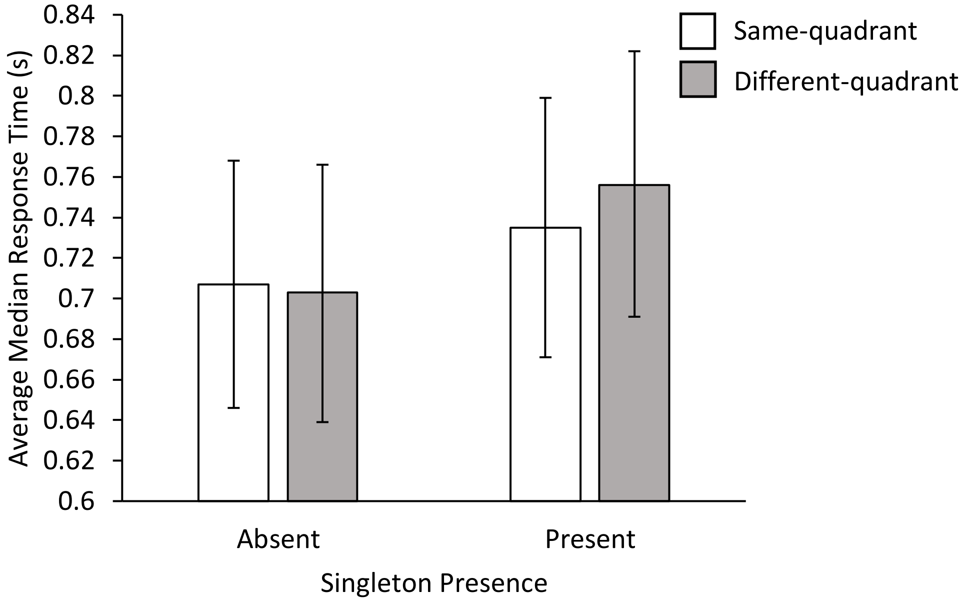

Figure 2.2. Average median response times (in seconds) on singleton-absent and singleton-present trials, when it was presented in the same-quadrant (white) and in a different-quadrant (grey) to the target. Error bars represent 95% confidence intervals.

Accuracy

A non-significant main effect of Singleton Presence was found (*F*(1, 14) = .106, *p* = .749, η_p^2 = .008). A main effect of Singleton Location was also not found (*F*(1, 14) = 1.25, *p* = .282, η_p^2 = .08; same-quadrant: M = .97, SE = .01 [95% CI .94, .99]; different-quadrant: M = .96, SE = .01 [95% CI .94, .98]). Critically, a significant Singleton Presence x Singleton Location interaction was found (*F*(1, 14) = 5.07, *p* = .041, η_p^2 = .27; *see Table 2.1 overleaf*). This showed that participants had better accuracy on singleton-present trials when the distracter was presented in the same quadrant as the target, relative to a different quadrant (*p* = .041). No difference was found between dummy same- and different-quadrants on singleton-absent trials (*p* = .435). Non-significant differences between singleton-present and singleton-absent trials were shown on both same-quadrant (*p* = .289) and different-quadrant levels (*p* = .055).

Table 2.1. Mean accuracy (*M*), standard error (*SE*) and 95% confidence intervals (*95% CI*) on singleton-absent and singleton-present trials, when it was located in the same- and different-quadrant to the target.

	Singleton-Absent		*Singleton-Present*	
	Same-quad	*Different-quad*	*Same-quad*	*Different-quad*
M	.96	.97	.97	.95
SE	.01	.01	.01	.01
95% CI	.94, .98	.95, .98	.95, 1.00	.93, .97

Note: Same-quad = same-quadrant; Different-quad = different-quadrant

Discussion

This study investigated attentional capture for a shape singleton distracter using the additional singleton paradigm. Specifically, I questioned whether a shape singleton distracter which had a unique feature value from coloured circle items in the display, would cause attentional capture. The findings showed a moderate attentional capture effect, as the black diamond shape singleton slowed response times by 41ms when it was present in the search-display, compared to when it was absent. In addition, I assessed whether the location of the singleton distracter in the search-display influenced search for the target. Overall, I found that the location of the singleton distracter had little influence on response times but it did lead to better accuracy when it was located closer to the target, relative to when it was further away. I will discuss each finding and the relevant limitations in turn.

The results indicate that a singleton distracter defined by a disparity in the shape dimension, can cause attentional capture. In particular, a shape singleton distracter can cause an attentional shift when it is present amongst a homogenous display of circles. Bottom-up and hybrid accounts of attentional capture and selection would suggest that the local contrast in the display would lead activations for the diamond feature to be enhanced relative to the circle feature values (Theeuwes, 2010; Wolfe et al., 1989; Wolfe, 2014). Perceptual grouping for this unique diamond feature would be less prominent compared to the homogenous circle items (Duncan & Humphreys, 1989; Humphreys, 2016). If the circle items were grouped at the preattentive level, this could have reduced their saliency and therefore the saliency of the target in relation to the singleton distracter (Humphreys, 2016). In addition to this, the singleton distracter had high contrast edges relative to the blurred circle edges which is known to reduce saliency at the local and global object level (Mevorach et al., 2005, 2009; Tsvetanov et al., 2013). As a result, attention may have been driven towards the most salient item in the display (i.e. the singleton distracter) as predicted by the "winner take all" principle of saliency computations in the master feature map (Desimone & Duncan, 1995; Wolfe et al., 1989; Wolfe, 2014). Therefore, a combination of disparities in the shape dimension and orientation (edges) dimension may have caused attentional capture in the singleton distracter used in this study.

The current findings add to the existing attentional capture literature. Previous research in this field has often used a colour singleton distracter to create capture effects and assess top-down modulation on this item (Bacon & Egeth, 1994; Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017; Jannati et al., 2013). As a result, the attentional capture literature has often questioned capture effects in other feature dimensions (Gaspelin et al., 2017; Liesefeld et al., 2018). The findings add to the field by showing that a shape singleton distracter can cause moderate capture effects (41ms), even when it was displayed amongst colourful stimuli (Gaspar, Christie, Prime, Jolicoeur & McDonald, 2016 – 21ms; Forster & Lavie, 2008 – Exp 1: 37ms – 52ms, Theeuwes, 2004 – Exp 1: 65ms; Liesefeld et al., 2017 – 225ms). This opposes previous research which did not find significant attentional capture effects for a shape singleton distracter, but only found this effect for a colour singleton (Christie, Spalek & McDonald, 2018; Theeuwes, 1991, 1992). It was argued that the saliency computations for local contrast in shape features are slower to become available in time, compared to local contrast in colour features (Theeuwes, 1992). It is worth noting that my study aimed to enhance the bottom-up saliency associated with the singleton distracter and included multiple feature disparities (i.e. it was an edged diamond amongst blurred circles), which are known to enlarge capture effects compared to singular feature disparities (Nothdurft, 2000). Therefore, it is possible that a combination of features may have caused an attentional shift towards the singleton distracter in my study and future research can further explore the specific effects of this by investigating each unique disparity in isolation.

The findings for the additional aim of this study showed that the distance between the target and the singleton distracter influenced performance. The attentional window hypothesis predicted that participants may experience more attentional capture when the target and the singleton distracter are close to one another, relative to further away (Belopolsky et al., 2007; Theeuwes, 2010; Theeuwes et al., 2004). As a result, this would lead to improved performance (faster response times, better accuracy) when searching for a target located close by to the singleton distracter. In addition, the spatial surround suppression hypothesis further predicted that items (i.e. the target) surrounding the focus of attention (i.e. the singleton distracter) will be suppressed (slower response times, poorer accuracy) but it further stipulated that this does *not* occur for items *within* the focal attention area (Hopf et al., 2006; Tsotsos, 1995; Walter, Quigley & Mueller, 2014; Wong-Kee-You et al., 2019). The findings showed that close distances, relative to far distances, between the target and the singleton distracter benefited search, but this effect was limited to accuracy data. Response times were not modulated by singleton location, rather response times were slowed by the presence of the singleton distracter irrespective of its distance to the target. For accuracy however, the results showed that participants were significantly more accurate at responding to the target, when both items were in the same quadrant (close distances) relative to different quadrants (far distances). It is possible that when the singleton distracter caused an attentional shift towards it, the target also fell within the same focus of attention on same-quadrant trials. Although I did not find distance effects to influence response times for the target, the findings did show that closer distances improve selection for the target at the response level in facilitating accuracy for making a discriminatory judgement. Therefore, trials which presented the singleton distracter in the same quadrant as the target can benefit accuracy performance and so to control for this, I will exclude these trials from my analyses in future chapters with this task.

Limitations & Future Directions

Some may argue that by adding, rather than replacing, a singleton distracter item to the search-display, this may have increased the set size which could explain the increase in response times on singleton-present trials. Increases in set size have been shown to be linearly related to increases in response time due to the additional items in the search-display which require attentional deployment in serial search (Lavie, 1995; Treisman & Gelade, 1980). However, the finding of better accuracy on singleton-present trials when the singleton was located closer to the target, compared to further away, provides greater support for attentional capture for this item (Störmer, Alvarez & Cavanagh, 2014; Walter et al., 2014). As highlighted above, this finding suggests that attention was engaged by the singleton distracter and facilitated accuracy judgements for the target which was close by; further suggesting that the singleton distracter was not excluded when searching for the target. Nevertheless, to address this issue future research should explore whether increases in set size in this task lead to attentional capture effects. Specifically, evidence has indicated that manipulating the set size by adding more non-target items in the additional singleton paradigm, attentional capture effects increase linearly (Roque, Wright & Boot, 2016). By manipulating the set size of coloured circles, this can investigate whether attentional capture effects for the singleton distracter increase. Alternatively, if the shape singleton was used as the target item, one would expect non-significant changes in response time as a function of increases in set size (i.e. a flat search slope), as this would suggest the shape singleton target captured attention and was located preattentively or at the very least, it was not excluded from search (Treisman & Sato, 1990; Wolfe, 2014).

A second point to consider is whether search for a tilted line target amongst two vertical line targets encouraged participants to search for the discrepancy in the search-display. Research has argued that searching for a singleton target amongst a homogenous display, encourages participants to utilise a singleton detection mode (Bacon & Egeth, 1994; Eimer & Kiss, 2008; Lamy et al., 2004). As participants' task-goal is to search for the "odd one out" they are more likely to experience attentional capture, compared to when the target is not a singleton (e.g. search for a tilted target amongst differently tilted non-targets; Gaspar & Mcdonald, 2014; Jannati et al., 2013). Despite the coloured circles being heterogenous, the orientation of the lines were not varied. I further consider the influence of a singleton target, relative to a conjunctive target in Chapter 7.

Lastly, it is often difficult to disentangle bottom-up and top-down processes in the additional singleton paradigm (Bacon & Egeth, 1994). One may suggest that in low level vision, the 45° oriented edges of the diamond singleton share the target-defining feature with the 45° oriented target line. In the early visual pathways, the processing of an object's edges is often thought of as processing its skeletal structure (Mizzi & Michael, 2014; Won, Forloines, Zhou & Geng, 2020). As such, it is difficult to conclude without further investigation whether attentional capture by the shape singleton distracter in this task, was a result of either bottom-up or top-down saliency computations or an entanglement of both (Wolfe et al,. 1989; Wolfe, 2014).

Conclusion

To conclude, this study showed that a shape singleton distracter created medium attentional capture effects, in the additional singleton paradigm, when it was presented amongst a heterogenous display of coloured circles. This provides greater clarity concerning whether a discrepancy in the shape dimension can rival attentional selection for the target located within a coloured circle (Gaspelin et al., 2017; Liesefeld et al., 2018). Furthermore, I showed that the location of the singleton distracter influenced accuracy for discriminating the tilt of the target line, but not response times. In particular, when the singleton distracter was located in the same quadrant as the target, participants were more accurate relative to different quadrant trials. This may provide further evidence for attentional capture and its facilitation in engaging attention to a location which the target shared (Gaspar & McDonald, 2014). Having demonstrated that my singleton distracter causes attentional capture, I incorporated this item in the Cued Visual Search task used in empirical Chapters 3-7 with children (5-11 years) and adults. This allowed me to assess whether endogenous cue-utilisation can override an attentional capture response towards the singleton distracter across development.

Chapter 3: Endogenous Control is Insufficient for Preventing Attentional Capture in Children and Adults

Abstract

Adults are known to have developed the ability to selectively focus their attention in a goal-driven (endogenous) manner but it is less clear at what age children can endogenously control their attention and whether they behave similarly to adults when managing distractions. In this study I administered a child-adapted Cued Visual Search task to three age-groups: five- to six-year-olds, nine- to 11-year-olds and adults. Participants were provided with a cue which either guided their attention towards or away from an upcoming target. On some trials, a singleton distracter was presented which participants needed to ignore. Participants completed three conditions where the cues were: 1) usually helpful (Mostly Predictive), 2) usually unhelpful (Low Predictive) and 3) never helpful (Baseline) in guiding attention towards the target. The findings showed endogenous cue-utilisation develops with increasing age. Overall, nine- to 11-year-olds and adults, but not five- to six-year-olds, utilised the endogenous cues in the Mostly Predictive condition. However, all age-groups were unable to ignore the singleton distracter even when using endogenous control. Moreover, better maintenance ability was related to poorer inhibition ability in early-childhood, but these skills were no longer related further on in development. It was concluded that overall endogenous control is still developing in early-childhood, but an adult-like form of this skill has been acquired by mid-childhood. Furthermore, endogenous cue-utilisation may be insufficient for preventing attentional capture in both children and adults.

Introduction

In Chapter 1 I reviewed the concepts surrounding the development of endogenous control. Here they will be revisited and explored in more depth. Specifically, I will discuss and critique studies which have used variants of the Cued Visual Search task, to understand the role of endogenous cue-utilisation and attentional capture across development. This will highlight the potential gaps in knowledge which require further exploration and will form the foundation for my aims in the current chapter.

Endogenous Cue-Utilisation Development

Endogenous control is argued to gradually develop throughout childhood and adolescence before reaching "peak" levels in young adulthood (Goldberg et al., 2001; Jakobsen et al., 2013; Schul, Townsend & Stiles, 2003). In the early school years, children are theorised to undergo a key transition between ages five and six from using mainly exogenous control to using mainly endogenous control when it is possible (Munakata et al., 2012). Research suggests that endogenous control becomes "adult-like" by mid-childhood (nine to 11 years old; Goldberg et al., 2001; Leclerq & Siéroff, 2013; Pearson & Lane, 1990; Schul et al., 2003; Wainwright & Bryson, 2005). However, others suggest that it is not until age 12 and over when an "adult-like" endogenous control is acquired (Wong-Kee-You et al., 2019).

There has been mixed evidence with regard to whether endogenous control is evident in early-childhood. Research has investigated attentional guidance by measuring visual orienting responses towards a cued location (Posner, 1980). Studies which presented a predictive location cue on either the left or right of the search-display have shown that five- to six-year-olds were faster when the cue guided attention towards (valid cue) relative to away from (invalid cue) the upcoming target location (Brodeur & Enns, 1997; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2002, 2005). Moreover, research has shown that orienting attention in response to arrows, pointing hands and gaze cues stabilises from a young age and shows no developmental change between three and 11 years (Hermens, 2018; Jakobsen et al., 2013). A more recent study with five- to six-year-olds found an orienting effect (faster on valid vs invalid trials) in a manual reaction time task as well as when making saccadic responses to a location cue (Landry, Johnson, Fleming, Crewther & Chouinard, 2019). Specifically, Landry et al. (2019) theorised that manual responses may account for the differences found between young and older children in previous research (Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005), as saccadic responses suggested that the development of endogenous control stays relatively constant until age 11. These findings could indicate that the ability to encode a goal-relevant cue to anticipate an upcoming event has developed and stabilised between ages five to six.

Under more detailed scrutiny however, evidence has shown that when a location cue or arrow cue is presented to guide attention towards the upcoming target location, five- to six-year-olds tend to produce larger orienting effects (faster on valid vs invalid trials) in response to the cue compared to older children and adults (Brodeur & Enns, 1997; Jakobsen et al., 2013; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2002, 2005). Large orienting effects may, however, be a signpost for an inhibition deficit, as research suggests that on invalid trials young children are slower to disengage and reorient their attention as they find it difficult to inhibit the cued location (Brodeur & Boden, 2000; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2002).

Moreover, some research has compared attentional control abilities by manipulating the predictability of the cue so that in one block of trials, the cues usually guide attention towards the target (encouraging cue-utilisation) and in a second block of trials, the cues usually guide attention away from the target (discouraging cue-utilisation; Brodeur & Boden, 2000; Brodeur & Enns, 1997; Wainwright & Bryson, 2002, 2005). Evidence has shown that five- to six-year-olds tend to produce large orienting effects when the cue is usually valid as well as when it is usually invalid (Brodeur & Boden, 2000; Brodeur & Enns, 1997) but seven-year-olds tend to only orient to cues which are usually valid (Shimi et al., 2014). This suggests that five- to six-year-olds orient towards the cued location regardless of its predictiveness towards the target. They may be utilising exogenous control to orient their attention as it is the mere presence of this cue which produces a reflexive rather than a goal-directed response (Friesen, Ristic & Kingstone, 2004; Soto, Humphreys, & Rotshtein 2007; Soto et al., 2008; Theeuwes et al., 2006; Theeuwes & van der Burg, 2008). It is unclear therefore whether endogenous control has been acquired by ages five to six or whether this age-group rely on using an exogenous strategy in response to cues.

Despite the uncertainty in early-childhood, endogenous control continues to develop throughout childhood (Schul et al., 2003), although it remains unclear at what age endogenous orienting becomes adult-like. In the Cued Visual Search task, adults are able to endogenously utilise cues to guide their attention, when the cues are usually predictive of the target's location as well as when they are usually *un*predictive (Leclercq & Siéroff, 2013; Moher & Egeth, 2012; Woodman & Luck, 2007). In a Cued Visual Search task which presents the target in one of two locations, cues which are usually invalid can encourage endogenous control and benefit performance by informing participants where *not* to search for the target. Research has shown that at age seven, children voluntarily utilise endogenous cues that are usually predictive, which enables them to benefit from them in guiding attention towards the target and this ability continues to develop in children aged 11 (Brodeur & Boden, 2000; Brodeur & Enns, 1997; Goldberg et al., 2001; Lookadoo, Yang & Merrill, 2017; Pearson & Lane, 1990; Shimi et al., 2014). Moreover, only 10-year-olds, and not eight-year-olds, behaved similarly to adults by showing negative orienting (faster on invalid vs valid trials) in this type of task (Leclercq & Siéroff, 2013).

Similarly, in the anti-cue paradigm where participants must make an opposite response to the cue, nine- to 12-year-olds, and not six- to eight-year-olds, were able to strategically modulate their attention in response to the cue (Van Gerven, Hurks, Bovend'Eerdt & Adam, 2016). Indeed, Event Related Potential (ERP) evidence has shown that 10-year-olds showed similar posterior activity to adults during encoding for a cued item which would later be recalled, particularly those who had high cue-utilisation abilities (Shimi et al., 2015). These findings suggest that by mid-childhood children may have acquired an adult-like endogenous control as they show similar patterns in their orienting response and are able to strategically modulate their attention. This is heavily debated however, as others suggest that attentional abilities do not become adult-like until late-childhood and adolescence (Luna, Garver, Urban, Lazar & Sweeney, 2004; Schul et al., 2003; Wong-Kee-You et al., 2019).

There is, therefore, mixed evidence concerning the age at which endogenous control is acquired and whether this skill is comparable to adults during mid-childhood. More research is required to further our understanding of the development of endogenous orienting as well as to investigate whether this skill can be used to help manage interference.

Attentional Capture

Distraction or *attentional capture* is a rapid process whereby a stimulus captures attention within approximately 100ms of it appearing in our visual field (Müller & Findlay, 1988). Stimulus-driven theories define attentional capture as an automatic process which occurs outside of our own volition (Theeuwes, 2010). It is theorised that it is the physical characteristics of an object, or its *salience*, driven by the visual system, which guides our attention towards it (Theeuwes, 2004; Tsvetanov et al., 2013; Van der Stigchel et al., 2009). In contrast, goal-driven theories suggest that attentional capture is contingent on our goals as capture effects are produced when an irrelevant distracter matches a defining feature of the target (Folk et al., 1992; Eimer & Kiss, 2008). Based on our understanding of attentional capture, as well as the interference this causes on the ability to focus attention, it is vital to comprehend whether endogenous control can help children and adults to reduce or even prevent attentional capture.

Much evidence on the dynamic between endogenous control and the prevention of attentional capture has been conducted with adults, with little reflection on whether children are able to use this higher-order skill to reduce distraction. Research has shown that young children are unable to modulate their exogenous response towards a distraction (Iarocci et al., 2009). Moreover, evidence has shown that four- to five-year-olds are more vulnerable to distraction relative to adults in the capture contingency paradigm (Gaspelin et al., 2015). In this paradigm, participants are presented with a cue which is either compatible (matched the colour of the target) or incompatible (mismatched the colour of the target) with the featural colour of the upcoming target. Gaspelin et al. (2015) found that adults showed a compatibility effect (slower on compatible vs incompatible trials) on this task, which was taken as evidence that their attention was captured by cued information which matched the task-goal. In contrast to this, four- to five-year-olds did not show a compatibility effect. This suggests that they were unable to maintain the cue to make an anticipatory response to the target and as a result they were distracted by the cue regardless of whether it matched a feature of the target. Other research supports this finding, as a study using arrow cues found that five- to six-year-olds were unable to use informative cues to modulate their exogenous response towards a distracter which was presented prior to the search-display and was unpredictive of the upcoming target's location (Iarocci et al., 2009). This suggests that five- to six-year-olds have not yet acquired the ability to inhibit a prepotent response towards a salient distraction, despite being provided with early information about the upcoming target.

As with cue use and endogenous control, it remains unclear at what age children become adult-like in their ability to override interference. A highly distracting external environment has been shown to influence eight- to 12-year-olds' ability to selectively focus their attention on the go/no-go task (Rodrigues & Pandeirada, 2018). In support of this, in a Cued Visual Search task, children aged eight to 11 years were provided with a location cue to guide their attention towards a target but inhibit non-target distracters (Wong-Kee-You et al., 2019). Children aged eight to 11 were unable to suppress distracters which were surrounding the spatially cued target, and adult-like suppression was only attained for children aged 12 and above (Wong-Kee-You et al., 2019). Indeed, children aged six and nine behaved similarly when they were encouraged to search for a feature of the target (i.e. grey circle) and ignore a more salient but irrelevant non-target feature (i.e. black squares; Merrill & Conners, 2013). In this study both age-groups behaved similarly in singleton detection (encourages exogenous process) and feature search (encourages endogenous process), which may be due to children’s inability to suppress the more salient black non-target distracters displayed amongst the less salient grey target. Nine-year-olds were shown only to behave similarly to adults when they were required to search for a black target that was more salient than the surrounding grey non-target items. As such, the evidence suggests that nine- to 11-year-olds are still developing the ability to use endogenous control to inhibit a distraction.

On the other hand, cueing research has also found that 10-year-olds behave similarly to adults in utilising informative cues to reduce their exogenous response towards a distracter (Iarocci et al., 2009). Compared to six-year-olds, ten-year-olds were better at recovering from attentional capture from an exogenous location cue as well as better at orienting towards the cued location of the predictive arrow cue; both skills re-enacted similarly in adults. Indeed, Michael, Lété and Ducrot (2013) found in a visual search task that children aged seven to 11 years were all able to reduce distraction when the salient item was irrelevant 100% of the time (as opposed to 50%), but adult-like inhibition was only acquired by age 11. It is uncertain therefore whether the ability to endogenously inhibit an “attend to me” signal of a distraction using visual cues is reserved for adolescents and adults or whether this ability is acquired by mid-childhood.

Attentional Capture & Cued Visual Search

Endogenous task-goals have been shown to prevent attentional capture in adults. This has been shown when adults were either provided with explicit instructions or implicitly learnt which upcoming item they needed to ignore. In many of these instances, adults have shown a lack of attentional capture to a singleton distracter (Gaspar et al., 2016; Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017; Sawaki & Luck, 2010; Wang et al., 2019). Distracter frequency and learning that the singleton distracter will be more likely to appear in one location as opposed to other locations, has reliably been shown to reduce capture effects in adults (Leber, Gwinn, Hong & O’Toole, 2016; Wang & Theeuwes, 2018; Won, Forloines, Zhou & Geng, 2020; for a review, see Chelazzi et al., 2019). It is less understood whether cueing a feature of the target can lead to suppression of attentional capture in children and adults.

As discussed in Chapter 1, some research using the Cued Visual Search task has indicated that cueing the location or feature of the singleton distracter does not prevent or reduce attentional capture (Beck et al., 2018; Moher & Egeth, 2012). Others have expanded on this and have indicated distracter cueing can reduce attentional capture by engaging this item first before rapidly disengaging from it (Chang, Cunningham & Egeth, 2018). This suggests that endogenous cues cannot prevent capture at an early point in processing but rather after attention has been deployed towards this item (*rapid disengagement hypothesis*; Theeuwes, 2010). Studies which cued a feature of the target, have shown that setting this early task-goal can reduce distraction. Cueing a target feature was shown to reduce distraction for a non-target item (better than cueing a distracter feature), but it is uncertain how this applies to attentional capture as a singleton distracter was not investigated in this study (Arita et al., 2012). Others have found that word cues signalling whether the “target” or “distracter” would be a colour singleton, led to saccades away from the singleton distracter (Weaver, Paoletti & van Doest, 2014).

To my knowledge, the study conducted by Theeuwes and van der Burg (2008) explicitly assessed whether enhancing the signal for a feature of the target reduces attentional capture for a singleton distracter presented in the search-display. As highlighted in the previous Chapter 1, adults experienced significantly less distraction on valid trials in the mostly predictive block (80% valid : 20% invalid trials) relative to neutral trials in the baseline block (100% neutral trials) when a singleton distracter was present in the search-display. Although attentional capture was not prevented by the use of endogenous cues, it was reduced when adults were provided with a valid cue which helped them to anticipate and rapidly locate the target. This finding warrants further investigation to understand whether endogenous cue-utilisation can facilitate attentional capture or if it is due to an exogenous process, as claimed by the authors. Theeuwes and van der Burg (2008) concluded that the feature-based cue-utilisation in this task was a result of exogenous mechanisms as a previous study using this task showed significant cueing effects, despite the cue being unpredictive of the target (17% valid block condition; Theeuwes et al., 2006). However, Theeuwes and van der Burg's (2008) findings used a baseline block (100% neutral trials) as a comparison measure and so their results are indicative of capture suppression but further clarification is required.

I argue that feature-based cueing is not solely an exogenous process (for counter-argument, see Theewes, 2013). As emphasised in my discussion of attentional selection theories, items in our field of vision are processed at the bottom-up level with regard to their feature values (Desimone & Duncan, 1995; Treisman & Sato, 1990; Wolfe, 2014). A feature cue is also processed at this level, as colour cues have been shown to enhance the response of monkeys' colour-selective cells in V4 and human visual evoked potentials and response times for matching colours across the visual field (Adams & Chambers, 2012; Andersen et al., 2011; Martinovic et al., 2018; Motter, 1994). That is not to say that a cue cannot increase the attentional weight given to a feature as in fact, evidence has indicated that endogenous (and not exogenous) cue-utilisation is dependent on context (Yantis & Jonides, 1990). The predictive context of cues at the block level have been shown to influence cue-utilisation, with higher block predictiveness (~70% valid trials and above) leading to increased cueing effects relative to baseline and low predictive blocks (Brodeur & Boden, 2000; Carlisle & Woodman, 2011; Kiyonaga et al., 2012; Laarni, 2001; Mayer et al., 2004; Soto & Humphreys, 2007). Fundamentally, exogenous and endogenous cueing effects can be disentangled by comparing mostly predictive blocks to baseline or low predictive block conditions (Corbetta et al., 2000; Berger et al., 2005; Jonides, 1981; Soto et al., 2008).

A vast amount of research using feature cues has compared exogenous vs endogenous processes by manipulating block predictiveness. Studies using central arrow cues have shown that the reflexive nature of arrows can also be encompassed with an endogenous cue in mostly predictive contexts, as opposed to low predictive contexts (Friesen, Ristic & Kingstone, 2004; Jakobsen et al., 2013; for a review, see Ristic & Kingstone, 2006). Colour cueing effects have also been shown to be modulated by block predictiveness (Anderson, Heinke & Humphreys, 2011; Laarni, 2001). Hence, feature-based cues may produce a combination of exogenous and endogenous processes which is in line with the principles of hybrid attentional selection accounts (Bundesen, 1990; Found & Müller; Wolfe et al., 1989; Wolfe, 2014). Therefore, studies investigating endogenous cue-utilisation and attentional capture should aim to understand if predictive contexts (mostly predictive, low predictive, baseline) influence performance to fully ascertain the differences in attentional control processes used in the task.

Comparing maintenance and inhibition in development

It has been argued that maintenance and inhibition abilities are key components in orienting behaviour (Brodeur & Boden, 2000; Brodeur & Enns, 1997). Maintenance of the cue is required at an early point of processing to guide attention, whereas inhibition of distracters or invalidly cued locations is required to disengage and reorient attention (Berger et al., 2005; Soto et al., 2008; Wainwright & Bryson, 2005). This could suggest that maintenance and inhibition abilities are independent but related processes, required for the control of attentional orienting. Evidence has shown that endogenous orienting and reorienting processes enhance activity in similar neural substrates in the fronto-parietal regions (Berger et al., 2005; Corbetta et al., 2000; Kim et al., 1999). ERP research with adults has shown that the associated signals for cue-maintenance (N2pc) and distracter-inhibition (Pd) are independent processes used in attentional selection (Gaspar et al., 2016; Mertes, Wascher & Schneider, 2016). However, further clarification is required to understand the relationship between these processes, specifically whether one benefits the other (i.e. better maintenance leads to better inhibition).

It is possible that age may moderate the relationship between maintenance and inhibition in attentional orienting. Research suggests that there are differences in the developmental profiles for maintaining relevant information and inhibiting irrelevant information (Brodeur & Boden, 2000). Evidence has shown that the large orienting effects found for younger children are due to their inability to disengage their attention away from an item (on invalid trials; Brodeur & Boden, 2000; Brodeur & Enns, 1997; Leclercq & Siéroff, 2013). When a cue has guided attention towards a non-target location, participants must inhibit this location in order to disengage and reorient their attention to serially search for the target (Wainwright & Bryson, 2005). It is possible that the ability to maintain a cue to selectively orient attention has developed from a young age, but children's ability to inhibit irrelevant information does not develop until mid-childhood.

In general, developmental research suggests that older children appear to have better control over managing irrelevant information compared to younger children, both for dealing with a distraction (Iarocci et al., 2009; Michael et al., 2013) as well as for response inhibition (Van Gerven et al., 2016). It is also important to consider whether endogenous cues can reduce or prevent attentional capture in children and adults. As both maintenance and inhibition abilities are both spoken of as components of endogenous orienting (Brodeur & Boden, 2000; Chun, 2000; Leclercq & Siéroff, 2013; Michael et al., 2013; Wolfe et al., 1989), it is of interest to examine this area further to understand the relationship between these abilities and how they change with age.

The Current Study

In this study, I used a Cued Visual Search task to assess age-related differences in endogenous control and attentional capture. This task incorporated the search-display and singleton distracter developed in Chapter 2. Participants were asked to search for a white tilted line target presented in one of three coloured circles. They responded to the target by discriminating the direction of its tilt (L/R). Immediately prior to presenting the search-display, participants were presented with a coloured circle cue. Valid cues guided attention towards the target to assist search (e.g. blue cue – target presented in the blue circle). Invalid cues guided attention away from the target to hinder search (e.g. blue cue – target was not presented in blue).

As it has been difficult to disentangle endogenous and exogenous processes in previous research (Landry et al., 2019; Pearson & Lane, 1990; Wainwright & Bryson, 2005), I included conditions where the cues are mostly helpful (Mostly Predictive block; 66.67% valid cues: 33.33% invalid cues; aimed to encourage cue-use) to conditions where the cues are mostly unhelpful (Low Predictive block; 33.33% valid cues: 66.67% invalid cues; aimed to discourage cue-use) in order to compare endogenous and exogenous performance (Brodeur & Boden, 2000; Brodeur & Enns, 1997; Johnson, Lewis & Cornish, 2020; Leclercq & Siéroff, 2013). I also included a neutral cue (Baseline block; 100% of cues were neutral) which acted as a baseline measure for cue-utilisation as it neither guided attention towards or away from the target (blue cue – target was presented in any colour except blue as the blue circle was absent from the search-display; Soto et al., 2007). Finally, in each block condition, 41.67% of trials included a salient singleton distracter (a black diamond) in the search-display to assess attentional capture effects. The singleton distracter was presented below the chance level to ensure that participants did not learn to anticipate and suppress this item before processing the cue. Previous research has shown that frequencies above the chance level can encourage learning of distracter locations and distracter-inhibition (Wang & Theeuwes, 2018). As this thesis is interested in whether an early endogenous cue can reduce attentional capture, it was vital to reduce the influence of distracter frequency on performance to ensure participants were encouraged to utilise the cues to guide attention.

This study had three aims. First, I aimed to understand the age at which endogenous cues can be utilised to guide attention in a goal-driven manner. Specifically, I was interested in whether endogenous cue-utilisation has developed by early-childhood (5-6 years) and whether an adult-like form, similar to adults (18-25 years), has been acquired by mid-childhood (9-11 years). Endogenous control would be shown by large differences between valid and invalid response times and accuracy indicating high cue-utilisation. If endogenous control has developed, I would expect to find greater cue-utilisation in the Mostly Predictive block than the Low Predictive block and the Baseline block. Based on the findings of Leclercq and Siéroff (2013) and Iarocci et al. (2009), I predicted that nine- to 11-year-olds and adults would show this pattern of results, with adults having significantly greater cue-utilisation than nine- to 11-year-olds. It is uncertain however whether five- to six-year-olds will show greater cue-utilisation in the Mostly Predictive block compared to Baseline (Gaspelin et al., 2015; Johnson et al., 2020).

The second aim of the study was to investigate whether children and adults can utilise endogenous control to reduce attentional capture. To do this I compared performance when there was a singleton distracter present in the search-display compared to when it was absent. If endogenous control reduces attentional capture, I expected to find a smaller difference between singleton-present and singleton-absent trials in the Mostly Predictive block compared to the Low Predictive block and the Baseline block. It remains unknown whether children and adults are able to utilise endogenous cues to reduce attentional capture (Arita et al., 2012; Theeuwes & van der Burg, 2008).

The third aim of the study was to assess whether maintenance and inhibition abilities are related more generally, as research has argued that these skills are key components of endogenous orienting (Brodeur & Boden, 2000; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005). I assessed this by using cueing ratios (invalid / valid response times) on singleton-absent trials in the Mostly Predictive block as the measure for maintenance and distraction ratios (singleton-present / singleton-absent response times) in the Baseline block as the measure for inhibition. If maintenance and inhibition abilities are related, I expect to find a negative relationship; as the ability to maintain a cue increases, distraction caused by the singleton distracter decreases. However, age may moderate this relationship as research suggests that young children are still developing the ability to maintain and inhibit information (Broden & Bodeur, 2000; Broden & Enns, 1997; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005).

This study was pre-registered on the Open Science Framework (osf.io/cvj8p). It should be noted that the pre-registration for this study intended for cueing ratios (on singleton-absent trials), distraction ratios and untransformed median response times and mean accuracy to be calculated and used in the main analyses. All pre-registered analyses were conducted but additional analyses were also completed to further understand the main aims (to be highlighted in Results section).

Method

Participants

One hundred and twenty-nine participants from three age-groups (5-6, 9-11 & 18-25 years) took part in this study (*see Table 3.1 overleaf*) after exclusion (5-6 years: attrition = 5, failure to follow instructions = 3; 9-11 years: failure to follow instructions = 3; adults: failure to follow instructions = 3; experimenter error = 3, reported to have had a diagnosis of a mental health condition and/or developmental disorder = 3)[4]. Children were recruited from two primary schools and one infant school in the Derbyshire region between January and May 2018. The schools ranged from a 3rd to 10th multiple deprivation decile in the 2015 English Indices of Multiple Deprivation which measures relative deprivation ranking from the most deprived areas (smaller ranks) to the least deprived areas (larger ranks). Adults were undergraduate and postgraduate students from the University of Nottingham. This study was granted ethical approval by the University of Nottingham School of Psychology Ethics Committee. Parents and adults provided informed consent and verbal assent was gained from children. Adults were compensated for their time in the form of a course credit or an inconvenience allowance and

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[4] I conducted a power analysis using the method described by D'Amico, Neilands & Zambarano (2001) and Osborne (2006) (see osf.io/cvj8p). This method used pilot data to simulate an effect size to understand the number of participants needed for the required power. This found that 40 participants were required per age-group to attain a power of .8 at an alpha criterion of .05 for a simulated effect size of $\eta_p^2 = .051$. However, due to experimenter error in inputting the pilot data this power analysis was inaccurate. Correcting this error resulted in a simulated effect size of $\eta_p^2 = .076$ and required a sample size of 30 participants per age-group for the analysis of cue-utilisation in a Block x Age-Group interaction. Therefore I attained more than adequate power for this study.

children were compensated in the form of a certificate, stickers and a novelty pencil.

Table 3.1. Participant demographic information.

	5- to 6-year-olds	*9- to 11-year-olds*	*Adults*
N	45	42	42
M age (SD) (years)	5.98 (0.32)	10.43 (0.56)	20.47 (1.79)
Age range (years)	5.50 – 6.67	9.50 – 11.50	18.00 – 25.50
Gender Identity (m : f)	40% : 60%	42.86% : 57.14%	23.81% : 76.19%
Ethnicity	80% White, 8.89% Asian, 2.22% Black, 8.89% Mixed Ethnic Groups	92% White, 4.76% Asian, 2.38% Mixed Ethnic Groups	61.90% White, 28.57% Asian, 4.76% Black, 4.76% Mixed Ethnic Groups,
Bilingual	13.33%	2.38%	30.95%

Note: M – mean; SD – standard deviation; m – male; f - female.

Design

I used a mixed design which included three within-subject variables and one between-subject variable. Cue Validity was manipulated to guide participants' attention towards (valid cue) or away (invalid cue) from the target as well as not guide attention (neutral cue). Block Predictiveness manipulated cue validity over three block conditions in the Mostly Predictive block (66.67% valid: 33.33% invalid cues), Low Predictive block (33.33% valid: 66.67% invalid cues) and Baseline block (100% neutral cues; *for trial proportions see Table 3.2 in Results section*). Singleton Presence (present, absent) assessed attentional capture as a singleton distracter was present on 41.67% of trials in each block. Participants from three age-groups (5- to 6-, 9- to 11-years & adults) were invited to complete all three block conditions of the Cued Visual Search task in either a single 1 hour session (adults) or three 20 minute sessions (children) over a one to two week period. See *Figures 3.1A* and *3.1B* overleaf which continue providing an overview of the counterbalancing measures taken from *Figure 2.1* (*see page 37*).

Step 4 (Cue)

The cue is equally likely to be any of the 4 colours overall and guide attention to the target line in any of the 4 quadrants.
***Participants could not learn that they see a particular cue colour (e.g. pink cue) more often than other colours or that the cue colour informs them of the target's location (e.g. pink cue does not mean target is in upper-right corner)*.**

Step 5 (Cue Validity)

Mostly Predictive Block (66.67% valid: 33.33% invalid)

Participants learnt when they see any cue colour, this will usually guide them towards the matching colour target in any of the 4 quadrant locations. Example: there were 36 trials where the target was in the yellow circle equally distributed across 4 quadrants– 24 of these trials were valid (yellow cue- target in yellow) and 12 of these trials were invalid (yellow cue – target in pink, green or blue four times each). Therefore, overall, participants learn yellow cue predicts target in yellow (and not what quadrant of the search-display it appears in). This rule was applied to all colours and quadrant locations associated with the target.

Low Predictive Block (33.33% valid : 66.67% invalid)

Participants learnt that when they see any cue colour, this will usually guide them away from the matching colour target in any of the 4 quadrant locations. Example: there were 36 trials where the target was in the yellow circle equally distributed across 4 quadrants. **All of these trials were the same as the Mostly Predictive block, except I changed the colour of the cue for 12 of these trials.** This ensured that 24 trials were now invalid (yellow cue – target in pink, green or blue eight times each) and 12 trials were valid (yellow cue – target in yellow). From this example, you can see that the yellow target was cued by a non-matching colour more often than a matching colour. This same rule was applied to all other colours and locations associated with the target.

Baseline Block (100% neutral)

Participants learnt that the cue did not match any colour in the search-display. Example: in the 36 trials where the target was in the yellow circle, the colour of the cue was equally likely to be pink, green or blue (12 times each) and the cued colour was absent from the search-display. This pattern was replicated for all colours and locations associated with the target. **Critically, all trials matched the Mostly Predictive block, except for the colour of the cue.**

Figure 3.1A. Schematic representation of the steps involved in counterbalancing the cues in relation to the target and singleton distracter items in the search-display.

Step 6 (Cue Validity x Singleton Distracter)

It was important that participants could not learn to use the colour of the cue to inform them of:
-the singleton distracter’s location or the colour of the circle it was adjacent to
-whether the singleton distracter would be present or absent from the search-display
To achieve this, I made sure that the number of singleton-present trials were equally distributed to valid and invalid trials. This would ensure that participants would not learn to expect the singleton distracter to be present in the display in a context where most of the cues were valid or invalid.
Example: there were 15 (out of 36) trials where the target was in the yellow circle and a singleton distracter was present in the display. Eight of these trials were assigned a valid cue and the remaining 7 trials were assigned an invalid cue. This slight imbalance was propagated across all colours associated with the target. In addition, it was expected that an imbalance of 1 trial would not influence learned associations at this level. Critically, the validity of the cue in singleton-present trials was kept constant in the Mostly and Low Predictive block conditions.

Step 7 (Target Line Orientation)

The orientation of the target line was equally likely to be tilted left or right.
The cue colour and the location it guided attention could not inform participants of the tilt of the target.
The tilt of the target was equally likely to be valid (48 trials left and right) or invalid (24 trials left and right).
The number of singleton-present trials and its location in the search-display were equally likely to have a left or right tilted target.
Finally, the colour of the circle which included the target line and its location in the search-display, were equally likely to have a left or right tilted target.

Figure 3.1B. Schematic representation of the steps involved in counterbalancing the cues in relation to the target and singleton distracter items in the search-display.

Stimuli

The stimuli and search-display were replicated from Chapter 2. The key difference was the presentation of coloured circular cue (4.90° width x 4.90° height) in the centre of the screen, which preceded the search-display in each block condition (*see Figure 3.2 overleaf)*. All four colours included in the study were equally likely to be a cue. The cue was presented for 300ms before the presentation of the search-display which consisted of a fixation cross and three coloured circles with the same size properties as the cue. The cue was presented for 300ms as past research has shown endogenous orienting for display times 250ms and above (Berger et al., 2005; Corbetta et al., 2000; Jonides, 1981). All other displays in the trial sequence matched the method in Chapter 2.

Apparatus & Materials

The experiment was run using PsychoPy2 v1.85 (Peirce, 2008). The stimuli were presented on a different monitor to Chapter 2, which was slightly smaller in width (5.59° difference) and height (9.68° difference; LCD iiyama ProLite B2206WS monitor; 34.05° width x 23.06°). This monitor had been calibrated at a viewing distance of 70cm such that the relationship between voltage increments and luminance increments was linear and the red, green and blue colour channels were adjusted in accordance with this (Pelli & Zhang, 1991). As in Chapter 2, the stimuli were mirrored from an Apple MacBook Pro 2 laptop via DVI-D to Thunderbolt Apple Adapter connection. Both devices had a frame rate of 60Hz per/frame. Participant responses were recorded via an Apple keyboard connected to the Apple MacBook Pro 2 through USB. This experimental set-up allowed testing conditions to be portable across classroom and lab settings.

Procedure

Data collection was either carried out in a quiet classroom (child participants) or a university lab (adult participants) in darkened to minimal lighting conditions. To help the children to understand the instructions and to

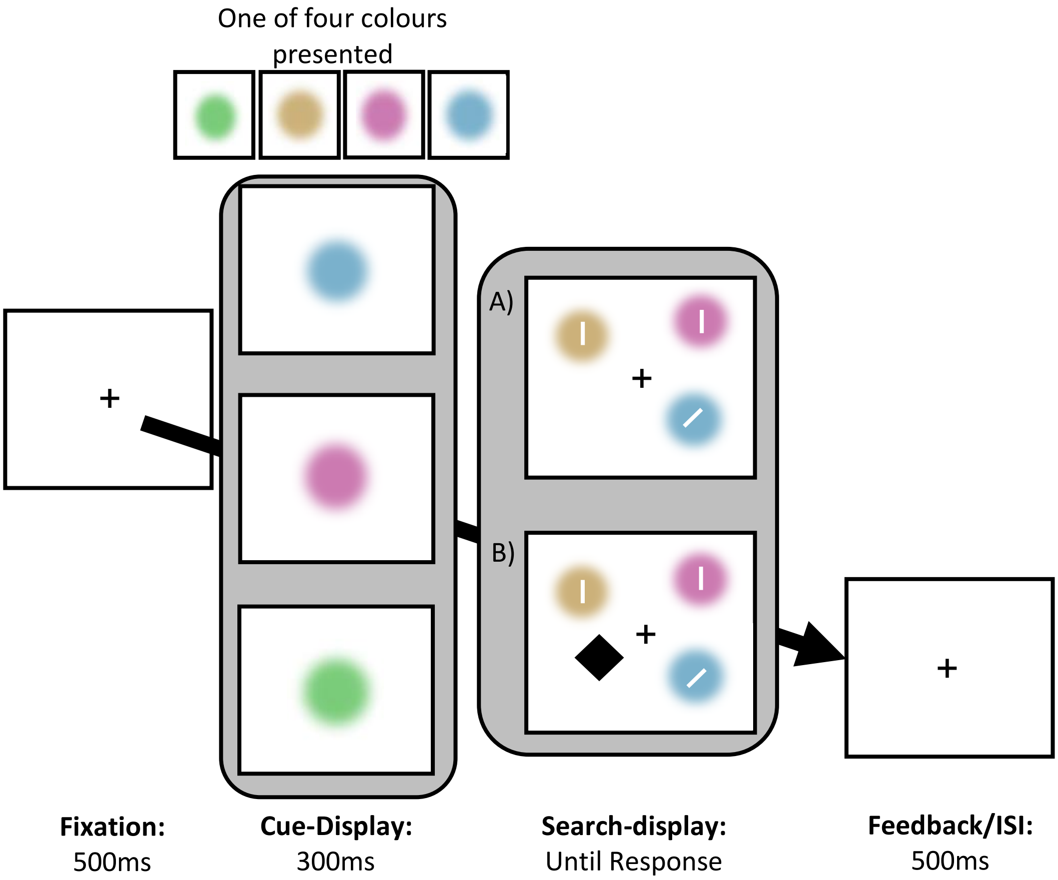

Figure 3.2. Schematic representation of the sequential order of the cued visual search task with time durations. Following fixation, only one of the four colours was presented in the Cue-Display. The Search-Display depicts a singleton-absent (A) and singleton-present (B) trial. In this trial, if the cue was valid, a blue cue would guide participants' attention towards the white tilted-line target in the blue circle. If the cue was invalid, a pink or a yellow cue would guide attention away from the target. If the cue was neutral, a green cue was expected to not guide attention towards or away from the target as this colour is not present in the search-display.

reduce fatigue, the experiment was designed as a game. Participants were asked to play the “Let’s Find Dory Game” by completing three different games on the computer. In the games they were told that popular cartoon character “Dory” was lost but she would provide them with clues (cues) to help them follow her trail (tilted-line target). Both children and adult participants were provided with the same instructions. No cartoon images or sound effects were presented within the experimental paradigm, but only during the instruction and break screens.

Practice Phases

Participants completed two phases of practice. The first (response practice; 9 trials), was to familiarise participants with the stimuli and key-responses as they were presented with the fixation cross, followed by the search-display (no cue; same trial sequence used in Chapter 2). They were instructed to press the ‘z’ key if the tilted-line was pointing towards the left and the ‘/’ if it was pointing towards the right (stickers were placed on the keys to help participants to locate them).

The second phase (cue practice; 9 trials), consisted of a fixation cross for 500ms, which was followed by the cue-display for 300ms. The search-display remained on the screen until a response was made. An inter-stimulus-interval of 500ms was applied for all trials. Visual feedback appeared as “Oops, wrong way!” in red Arial font for 500ms following inaccurate responses in all practice and experimental trials. Following cue practice, both children and adults were asked: “do you think Dory’s clues helped you find her trail/the tilted-line?” If participants responded with an incorrect response (“I’m not sure”, Low Predictive and Baseline blocks: “I think they were helpful”; Mostly Predictive block: “I don’t think they were helpful”), participants were asked to repeat the cue practice phase and were asked the same question again. If three or more trial responses were incorrect in any of the practice phases participants were asked to repeat the practice phase (once: 5-6 years: 20%; 9-11 years: 16.67% ; adults: 9.52%; twice: 5-6 years: 2.22%; 9-11 years: 4.76%; adults: 0%, across all block conditions). Both practice phases could be repeated up to three times each. If participants failed the practice by continuing to make three or more errors during these phases they were thanked for taking part and compensated for their time.

Experimental Phase

The experimental trials had the same stimulus presentation as the cue practice phase. Children completed a block condition (144 experimental trials per condition) in three 20-minute sessions on different days within a one- to two-week period. Adults completed three block conditions (288 experimental trials per condition) in a one-hour session. Three break periods were provided within each block condition. The order of the block conditions was counterbalanced[5].

Results

Data Processing

I aimed to compare performance in the Mostly and Low Predictive blocks to the Baseline block to accurately assess the level of cue-utilisation when participants are encouraged or discouraged from utilising the cue, compared to their baseline performance. For this purpose, I assigned valid and invalid labels to trials in the Baseline block (which only contained neutral trials). I assigned these labels to match trials in the Mostly Predictive block, to ensure that the search-display between the Mostly Predictive and Baseline blocks remained consistent but it was only the colour of the cue which was different between block conditions (see *Table 3.2 overleaf*)[6].

For the analysis, the first trial of each block and the first trial following a break period were removed from the data (2.78% data exclusion). Trials

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[5] There were six possible orders for the three block conditions. The order of the three block conditions was counterbalanced for nine- to 11-year-olds and adults. But the counterbalancing of order was not achieved for the five- to six-year-old age-group due to experimenter error with four participants. For this group, three orders (out of six) were repeated but no order was repeated more than one, or in one case, two additional times.

[6] The procedure for variable assignment differed from the pre-registered procedure. This is because random variation in sensory encoding between trials needed to be controlled for (Hillyard & Munte, 1984). I ensured variable assignment of all trials in the Baseline block matched the Mostly Predictive block.

where the singleton distracter shared a quadrant with the target were removed (8.33% data exclusion). This was because in Chapter 2 (no cue was presented) I found adults were significantly more accurate on these trials relative to other trials suggesting the singleton distracter facilitated responses to the target which warranted their removal from this analysis. All inaccurate trials (5-6 years: 3.90%; 9-11 years: 3.96%; adults: 3.12%) were filtered from the analysis of response times.

Outliers were assessed by removing trials which were +/- 4SD from a participant's median response time in a block condition. This led to 2.45% total data exclusion (5-6-years: 1.22%; 9-11-years: 0.63%; adults: 0.60%). Multivariate outliers for each age-group were assessed by calculating Mahalanobis Distance for all participants within each age-group across all response time and accuracy variables. No multivariate outliers were found.

Table 3.2. The proportion (%) (and number of trials) of valid and invalid cued trials in the Mostly and Low Predictive blocks, as well as the Baseline block following variable assignment. The proportion of singleton-absent and singleton-present trials are out of the total of valid or invalid cued trials they were assigned to.

Mostly Predictive block			
Valid Cues		*Invalid Cues*	
66.67% (96)		33.33% (48)	
Absent	*Present*	*Absent*	*Present*
68.75% (66)	31.25% (30)	37.50% (18)	62.50% (30)

Low Predictive block			
Valid Cues		*Invalid Cues*	
33.33% (48)		66.67% (96)	
Absent	*Present*	*Absent*	*Present*
37.50% (18)	62.50% (30)	68.75% (66)	31.25% (30)

Baseline block			
Assigned Valid Cues		*Assigned Invalid Cues*	
66.67% (96)		33.33% (48)	
Absent	*Present*	*Absent*	*Present*
68.75% (66)	31.25% (30)	37.50% (18)	62.50% (30)

For all analyses conducted, Greenhouse Geisser Correction was used when Mauchly's Test of Sphericity was violated ($p < .05$). All simple main effects analysis had Bonferroni Correction applied. An alpha criterion of .05 was used as the significance level.

Endogenous Control

Response Times

To measure cue-utilisation whilst controlling for differences in response times between age-groups, I calculated cueing ratios by dividing participants' invalid median response time by their valid median response time when the singleton distracter was absent from the display[7]. A cueing ratio greater than 1 suggests the participant utilised the cue to guide their attention. A 3 (Age-Group: 5-6-, 9-11-year-olds, adults) x 3 (Block Predictiveness: Mostly Predictive, Low Predictive, Baseline) mixed Analysis of Variance (ANOVA) was conducted on average cueing ratios for when the singleton distracter was absent to assess the development of cue-utilisation across age and block conditions. To investigate whether Singleton Presence influenced cue-utilisation, please see Appendix 3.1.

A significant main effect of Block Predictiveness was found ($F(1.76, 222.16) = 62.07$, $p < .001$, $\eta_p^2 = .33$). Average cueing ratios in the Mostly Predictive block (M = 1.18, SE = .02 [95% CI 1.15, 1.22]) were significantly larger than the Baseline block (M = .99, SE = .01 [95% CI .97, 1.01]; $p < .001$) and the Low Predictive block (M = 1.08, SE = .01 [95% CI 1.06, 1.10]; $p < .001$). Cueing ratios were significantly larger in the Low Predictive block relative to the Baseline block ($p < .001$). A significant main effect of Age-Group was also found ($F(2, 126) = 12.80$, $p < .001$, $\eta_p^2 = .17$), which shows that cueing ratios

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[7] Past research has calculated cueing effects using difference scores (invalid RT – valid RT; Brodeur & Boden, 2000). However, without z-transformation, this measure does not control for age-related differences in response times (Goldberg et al., 2001). Ratio scores are effective for measuring the contrast in performance between invalid and valid trials whilst also controlling for slowing between age-groups. This measure also provides a definitive level for cue-utilisation (ratios above 1).
Cueing ratios were calculated for singleton-absent trials to acquire a measure of cue-utilisation without the singleton distracter. Counterbalancing ensured participants could not learn to expect the singleton distracter from the cue colour.

were significantly smaller for five- to six-year-olds (M = 1.03, SE = .01 [95% CI 1.00, 1.06]) than nine- to 11-year-olds (M = 1.09, SE = .02 [95% CI 1.06, 1.12]; *p* = .007) and adults (M = 1.13, SE = .02 [95% CI 1.10, 1.16]; *p* < .001). Cueing ratios did not significantly differ between nine- to 11-year-olds and adults (*p* = .203).

A significant Age-Group x Block Predictiveness interaction was found ($F(3.53, 222.16) = 8.88$, $p < .001$, $\eta_p^2 = .12$; see *Figure 3.3*). In five- to six-year-olds, cueing ratios in all block conditions did not significantly differ from one another (all *p*s > .200). In nine- to 11-year-olds and adults, cueing ratios were significantly larger in the Mostly Predictive block relative to the Baseline block and the Low Predictive block (all *p*s < .001). In both of these age-groups, cueing ratios in the Low Predictive block were also significantly larger than the Baseline block (9-11 years: *p* = .005; adults: *p* < .001). Comparisons between

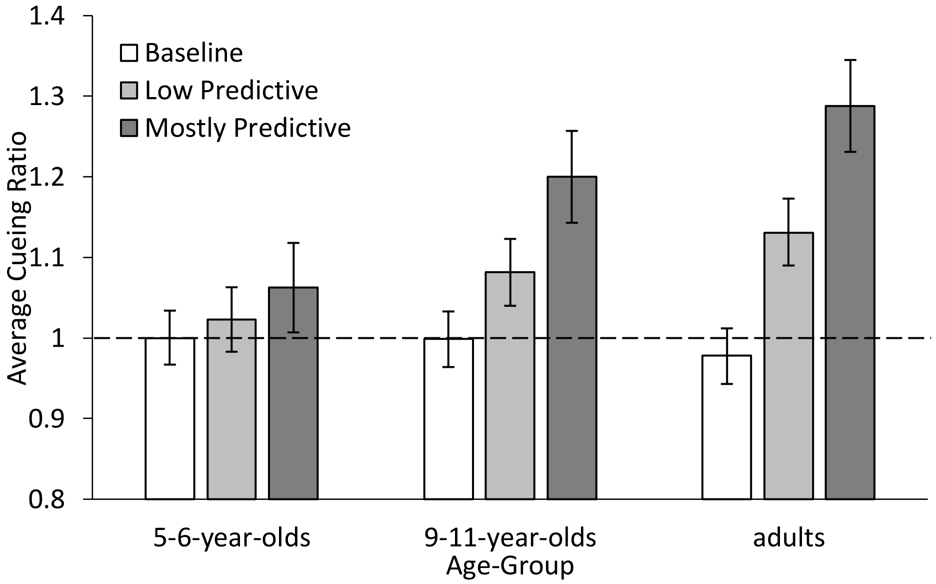

Figure 3.3. Average Cueing Ratios on singleton-absent trials for the Baseline block (white bars), Low Predictive block (light grey bars) and Mostly Predictive block (dark grey bars) across three age-groups. Average cueing ratio above 1 suggests cue-use for guiding attention. Error bars represent 95% Confidence Intervals.

age-groups show that in the Low Predictive block, cueing ratios for five- to six-year-olds did not significantly differ from nine- to 11-year-olds (*p* = .140), but they were significantly smaller than adults (*p* = .001). Cueing ratios for nine- to 11-year-olds in the Low Predictive block did not significantly differ from adults (*p* = .287). In the Mostly Predictive block, cueing ratios were smaller for five- to six-year-olds relative to nine- to 11-year-olds (*p* = .002) and adults (*p* < .001). Cueing ratios did not significantly differ between nine- to 11-year-olds and adults in the Mostly Predictive block (*p* = .100). All cueing ratios in the Baseline block did not significantly differ between age-groups (all *ps* = 1.00).

Accuracy

Cueing ratios were calculated for each participant by dividing their accuracy on valid trials by their accuracy on invalid trials for when the singleton distracter was absent from the display. A cueing ratio greater than 1 suggests cue-utilisation for guiding attention. A 3 (Age-Group) x 3 (Block Predictiveness) mixed ANOVA was conducted on cueing ratios for accuracy on singleton-absent trials. A main effect of Block Predictiveness was found (*F*(1.50, 189.31) = 9.79, *p* < .001, η_p^2 = .07). This showed that cueing ratios in the Mostly Predictive block (M = 1.03, SE = .01 [95% CI 1.01, 1.05]) were significantly larger than in the Low Predictive block (M = 1.01, SE = .004 [95% CI 1.00, 1.01]; *p* = .034) and Baseline block (M = .99, SE = .01 [95% CI .98, 1.00]; *p* = .001). Cueing ratios in the Low Predictive block did not significantly differ from the Baseline block (*p* = .098). The main effect of Age-Group was not significant (*F*(2, 126) = .26, *p* = .77, η_p^2 = .004) and the Age-Group x Block Predictiveness interaction was also not significant (*F*(3.01, 189.31) = 1.22, *p* = .304, η_p^2 = .02; *see Table 3.3*).

Attentional Capture

Response Times

I calculated distraction ratios by dividing participants' median RT on singleton-present trials by their median RT on singleton-absent trials[8].

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[8] As with cueing effects, attentional capture effects are often calculated using difference scores (singleton-present response time – singleton-absent response time) with adults (Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017; Liesefeld et al., 2017). Ratio scores

Table 3.3. Average cueing ratio (Standard Error [95% Confidence Intervals]) for accuracy data on singleton-absent trials for Mostly Predictive, Low Predictive and Baseline blocks across three age-groups.

	5- 6-year-olds	*9- 11-year-olds*	*Adults*
Mostly Predictive	1.02 (.02 [.99, 1.05])	1.05 (.02 [1.02, 1.09])	1.03 (.02 [1.00, 1.06])
Low Predictive	1.00 (.01 [.99, 1.02])	1.00 (.01 [.99, 1.02])	1.01 (.01, [1.00, 1.02])
Baseline	1.00 (.01 [.98, 1.01])	.98 (.01 [.97, 1.00])	1.00 (.01 [.98, 1.01])

Distraction ratios which are greater than 1 suggest high levels of distraction by the singleton distracter. To understand whether endogenous cues reduce capture across all age-groups, I conducted my analyses using distraction ratio scores. This simplifies the measure of distraction and its interpretation compared to our pre-registration and thus must be considered exploratory. I also conducted the four-way mixed ANOVA as per the pre-registration and report this in Appendix 3.2. It should be noted that the findings from both statistical tests were consistent with one another.

I explored whether the singleton distracter caused attentional capture in general by conducting Bonferroni corrected one-sample t-tests for each age-group on average distraction ratios in the Baseline block. This was conducted for the Baseline block only, as this condition isolates the effect of the singleton distracter with little influence from the cue. I found that the distraction ratios in the Baseline block for all three age-groups were significantly greater than 1 (5-6-year-olds: $t(44) = 3.54$, $p = .001$, two-tailed, M = 1.06, SE = .02 [95% CI 1.02, 1.09]); 9-11-year-olds: $t(41) = 7.37$, $p < .001$, two-tailed, M = 1.09, SE = .01 [95% CI 1.07, 1.11]; adults: $t(41) = 6.70$, $p < .001$, two-tailed, M = 1.05, SE = .01 [95% CI 1.03, 1.06]).

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can be used to assess the contrast in performance on these trials whilst also controlling for age-related differences in response times. Ratios above 1 provide a definitive measure of attentional capture.

To assess whether cue-utilisation influences distraction across cue validity and block conditions, a 3 (Age-Group) x 2 (Cue Validity: valid, invalid) x 3 (Block Predictiveness: Mostly Predictive, Low Predictive, Baseline) mixed ANOVA was conducted on average distraction ratios. The Age-Group x Cue Validity x Block Predictiveness interaction was not significant ($F(4, 252) = .70$, $p = .595$, $\eta_p^2 = .01$; *see Figure 3.4).* A main effect of Cue Validity was significant ($F(1, 126) = 4.06$, $p = .046$, $\eta_p^2 = .03$), which showed that distraction ratios were larger on invalid trials (M = 1.08, SE = .01 [95% CI 1.07, 1.09]) than valid trials (M = 1.06, SE = .01 [95% CI 1.05, 1.07]). A main effect of Age-Group was also found ($F(2, 126) = 4.60$, $p = .012$, $\eta_p^2 = .07$). Distraction ratios for five- to six-year-olds (M = 1.08, SE = .01 [95% CI 1.06, 1.09]) did not differ from nine- to 11-year-olds (M = 1.08, SE = .01 [95% CI 1.07, 1.10]; $p = 1.00$), but they were larger than adults (M = 1.05, SE = .01 [95% CI 1.03, 1.07]; $p = .047$). Nine- to 11-year-olds also had significantly larger distraction ratios than adults ($p = .019$). All other main effects and interactions were non-significant.

Accuracy

Distraction ratios were calculated for accuracy data (singleton-absent / singleton-present average accuracy; *see also Appendix 3.2*). A 3 (Age-Group) x 2 (Cue Validity) x 3 (Block Predictiveness) mixed ANOVA was conducted on distraction ratios for accuracy data. The Age-Group x Cue Validity x Block Predictiveness interaction was non-significant ($F(4, 252) = .58$, $p = .675$, $\eta_p^2 = 0.01$; *see Table 3.4).* All other main effects and interactions were non-significant (all *ps* > .05).

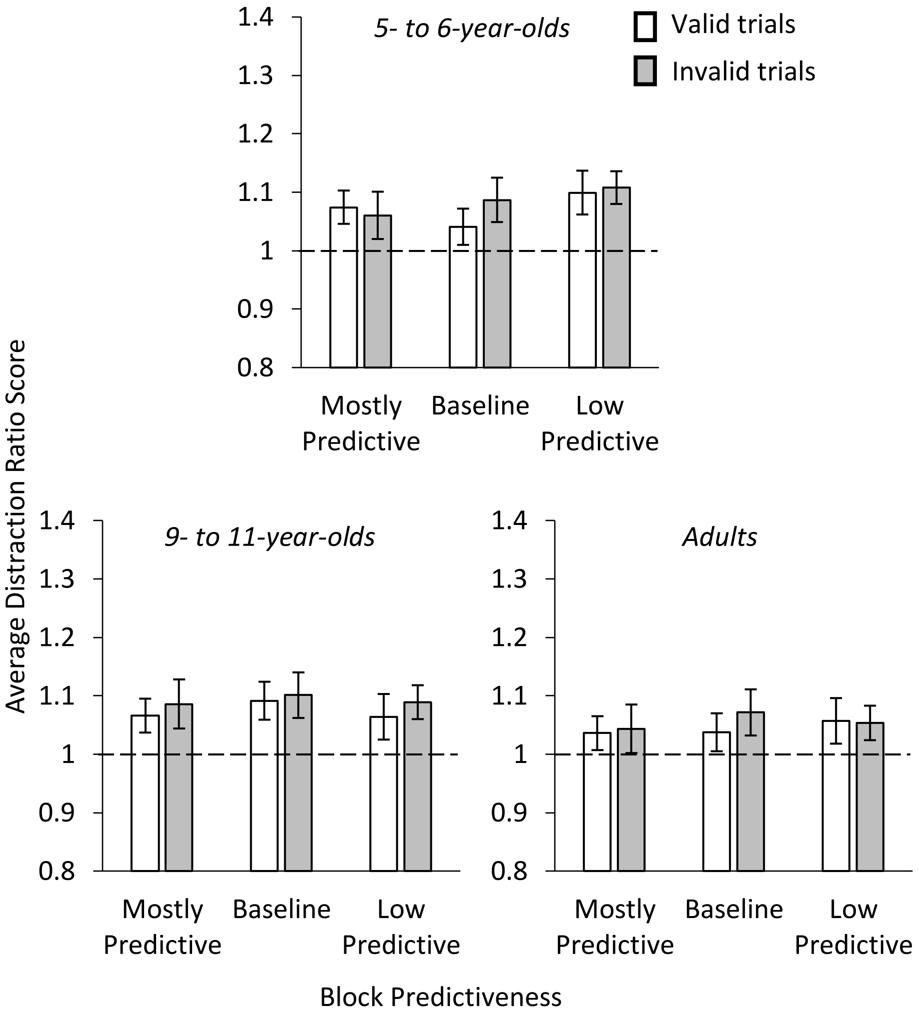

Figure 3.4. Average Distraction Ratio Scores for valid (white bars) and invalid (grey bars) trials in the Mostly Predictive, Low Predictive and Baseline blocks across three age-groups. Error bars represent 95% Confidence Intervals.

Table 3.4. Average distraction ratio (Standard Error [95% Confidence Intervals]) for accuracy data across block and cue validity for three age-groups.

		5- to 6-year-olds	*9- to 11-year-olds*	*Adults*
Mostly Predictive	*Valid*	1.01 (.01 [.99, 1.02])	1.01 (.01 [.99, 1.02])	1.01 (.01 [.99, 1.02])
	Invalid	1.00 (.01 [.98, 1.02])	.99 (.01 [.97, 1.02])	.99 (.01 [.97, 1.01])
Low Predictive	*Valid*	1.01 (.01 [1.00, 1.03])	1.00 (.01 [.98, 1.02])	1.01 (.01 [.99, 1.03])
	Invalid	1.01 (.01 [.99, 1.02])	1.01 (.01 [1.00, 1.02])	1.00 (.01 [.99, 1.01])
Baseline	*Valid*	1.00 (.01 [.99, 1.01])	.99 (.01 [.98, 1.01])	1.00 (.01 [.99, 1.01])
	Invalid	1.00 (.01 [.98, 1.01])	1.02 (.01 [1.00, 1.04])	1.00 (.01 [.99, 1.02)

Comparing maintenance and inhibition in development

I aimed to understand if the ability to maintain information for guiding attention and the ability to inhibit irrelevant information are related processes in Cued Visual Search. I predicted that this would be shown in a negative relationship, with distraction caused by the singleton distracter decreasing as the ability to maintain a cue increases. I assessed the relationship between cueing ability and inhibition ability within each block condition for each age-group. I investigated this aim by calculating Pearsons' Correlation Coefficients, with Bonferroni correction applied, for each age-group to analyse the relationship between cueing ratios and distraction ratios within each block condition. This aim was interested in the *general* use of maintenance and inhibition abilities within each block of the Cued Visual Search task, irrespective of the manipulated variables in each condition (i.e. singleton-absent vs singleton-present; valid vs invalid cue). Due to this, cueing ratios were calculated using data which aggregated across singleton-absent and singleton-present trials, as were distraction ratios calculated using data aggregated across valid and invalid trials. To consider maintenance and inhibition abilities *independently* within the Cued Visual Search task, I conducted an exploratory analysis which took a more targeted approach (to be discussed; *see page 81*).

Response Time

In the Mostly Predictive block, larger cueing ratios were associated with larger distraction ratios for all age-groups, but this positive relationship was significant in nine- to 11-year-olds ($r(41) = .707$, $p < .001$) and adults only ($r(41) = .829$, $p < .001$; *see Figure 3.5 overleaf*). In the Low Predictive block, larger cueing ratios were associated with smaller distraction ratios for all age-groups, but this negative relationship was only significant in five- to six-year-olds ($r(44) = -.494$, $p = .001$) and adults ($r(41) = -.764$, $p < .001$). Lastly, in the Baseline block a positive relationship was found between cueing ratios and distraction ratios with significance being met in adults only ($r(41) = .687$, $p < .001$).

It should be noted that there were six individuals in the five- to six-year-old age-group who had distraction ratios which were less than 1 (ranged from .88 - .98) in the Mostly Predictive block; suggestive of reduced distraction (faster on singleton-present vs singleton-absent trials) or no distraction. Five of these individuals had cueing ratios greater than 1 in this block condition, which suggests that some five- to six-year-olds may have made better use of the Mostly Predictive cues to limit distraction. If some five- to six-year-olds have “transitioned” and are better at using cues to limit their distraction than others in this age-group, one would expect to find a negative correlation which shows better cue-use to be related to reduced distraction. However, this was not found as exemplified by the non-significant positive correlation. Furthermore, distraction ratios were calculated across valid and invalid trials and so it is difficult to disentangle this result. A more targeted approach was used to further understand group and individual differences in maintenance and inhibition ability (*see page 81*).

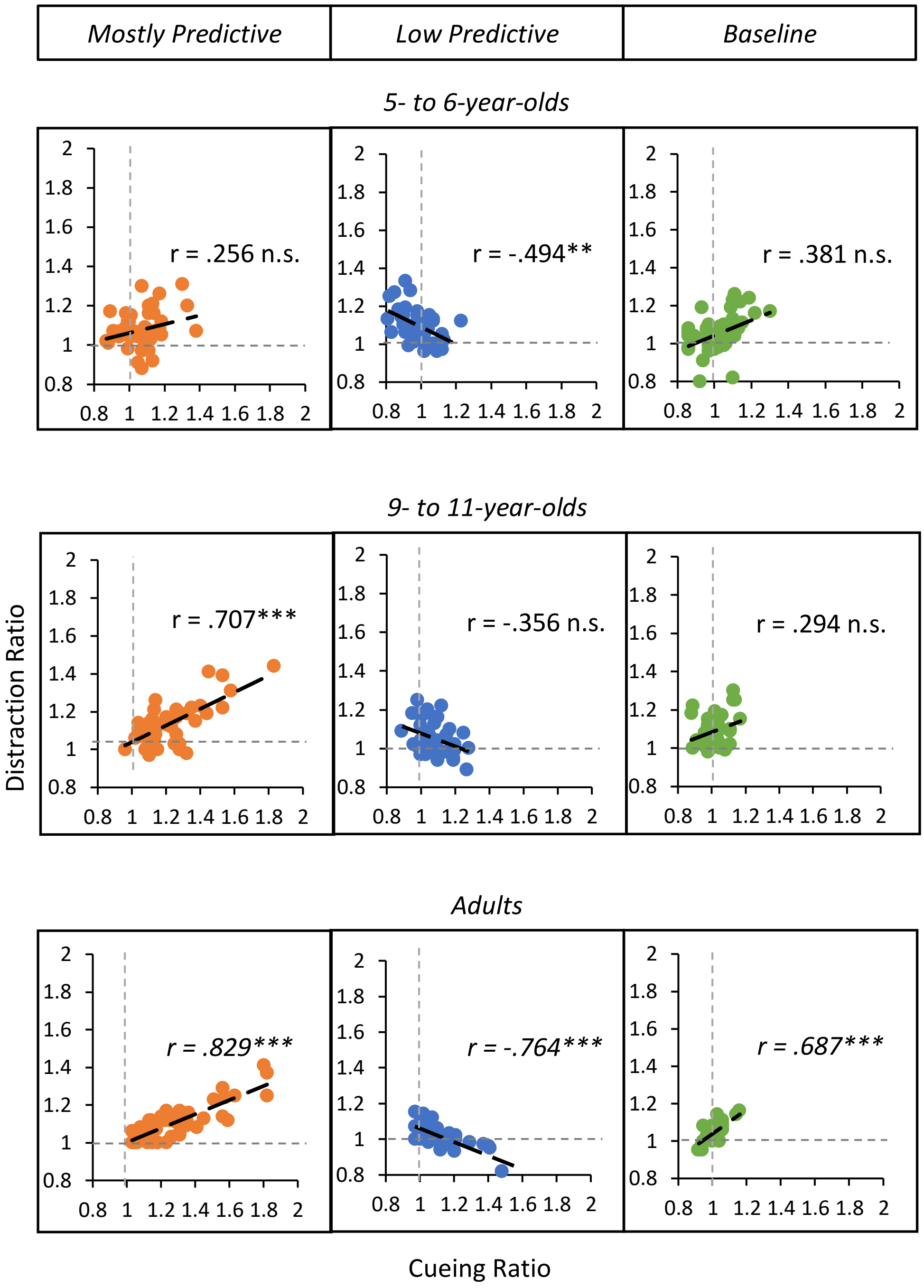

Figure 3.5. The relationship between cueing ratios and distraction ratios, for response times, within each block condition: Mostly Predictive block (orange), Low Predictive block (blue) and Baseline block (green). Pearson Correlation Coefficients (r) presented for each age-group.

Note: n.s. non-significant, * p < .05, ** p < .01, *** p < .001.

Accuracy

A similar pattern of results was found as shown in response times (*see Figure 3.6 overleaf*). All age-groups showed a positive correlation between cueing ratios and distraction ratios in the Mostly Predictive block and the Baseline block, but all coefficients were non-significant (*all ps* > .05). In the Low Predictive block, all age-groups showed a negative correlation between cueing ratios and distraction ratios which only met significance in adults ($r(41) = -.491$, $p = .001$).

Hierarchical Multiple Regression

I further explored this aim by using a moderation analysis to assess the predictive relationship between these skills when measured *independently* in separate block conditions. Whilst this analysis differs from the pre-registered approach above, I believe that this is the most methodologically rigorous approach as it examines the two skills independently and directly compares age-groups and therefore I have interpreted these results. For the measure of maintenance, I used response time cueing ratios in the Mostly Predictive block (on trials when the singleton distracter was absent from the search-display). I used response time distraction ratio scores from the Baseline block as a measure of inhibition of the singleton distracter. This targeted approach allowed me to consider maintenance and inhibition abilities by reducing the influence of singleton-presence on cueing ratios and the influence of cue validity on distraction ratios. Distraction ratios for each age-group in the Baseline block ranged from: 0.78 – 1.26 (5-6 years), 0.98 – 1.30 (9-11 years) and 0.95 – 1.16 (adults), with distraction ratios above 1 indicating greater distraction.

I conducted a hierarchical multiple regression (all assumptions were met) to assess the relationship of maintenance ability on inhibition ability and whether age moderates this relationship. Specifically, I wanted to see if the relationship between the amount of cue-use on the amount of distraction experienced is different in early- vs mid-childhood as well as mid-childhood vs adults. To make age group comparisons, I created dummy variables by

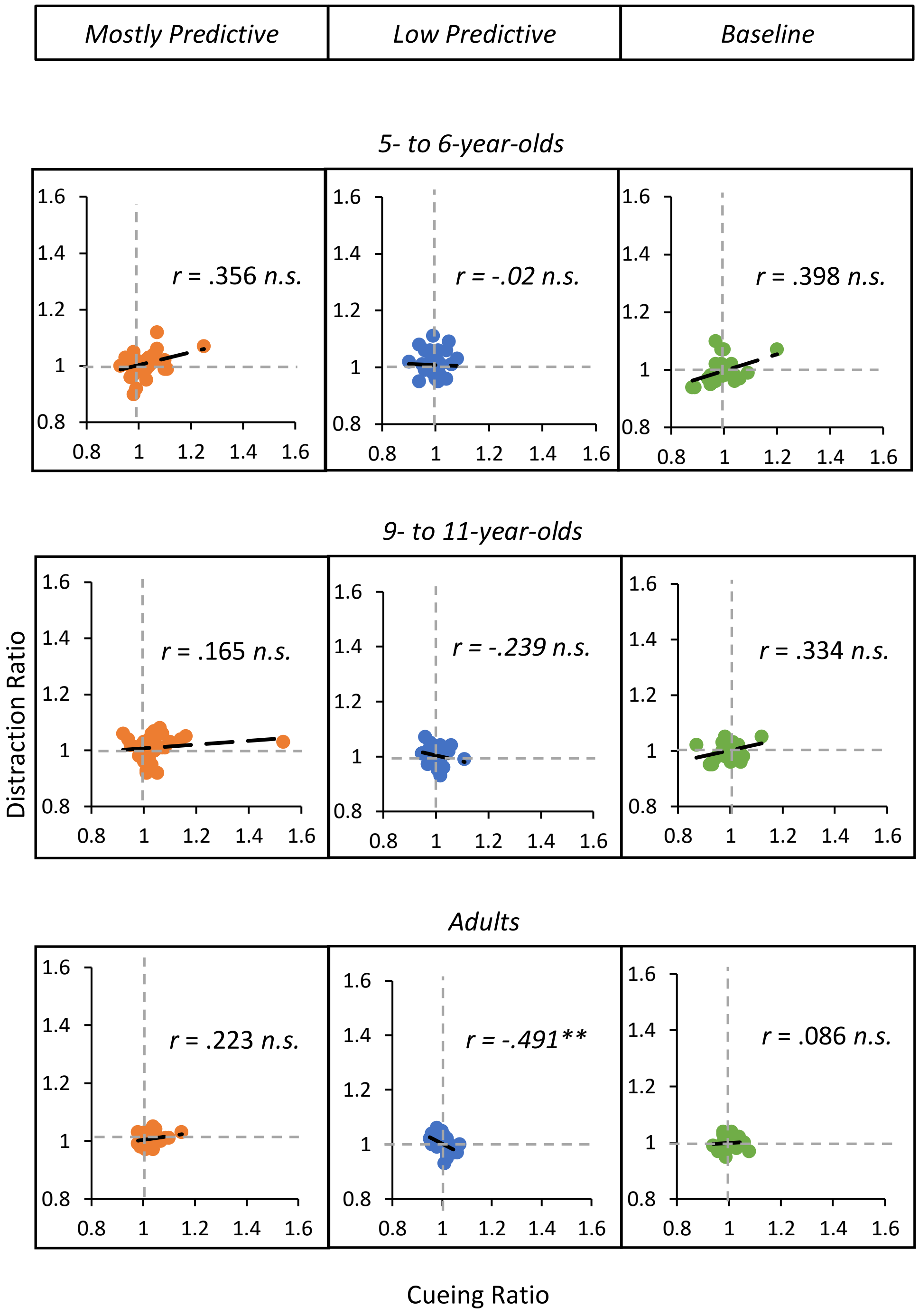

Figure 3.6. The relationship between cueing ratios and distraction ratios, for accuracy, within each block condition: Mostly Predictive block (orange), Low Predictive block (blue) and Baseline block (green). Pearson Correlation Coefficients (r) presented for each age-group.
Note: n.s. non-significant, * p < .05, ** p < .01, *** p < .001.

assigning weights (0, 1 & -1) to compare: 1) five- to six-year-olds and nine- to 11-year-olds and, 2) nine- 11-year-olds and adults. To assess whether age had a moderating effect, I created interaction terms by multiplying each participant's cueing ratio by the assigned weight in the dummy variables. This resulted in two interaction terms: Cueing x Young vs Older Children and Cueing x Older Children vs Adults.

Distraction ratios in the Baseline block was the outcome variable and the predictor variables were included in two models. Model 1 consisted of: cueing ratios in the Mostly Predictive block, Young vs Older Children Dummy Variable, Older Children vs Adult Dummy Variable. Model 2 consisted of the two additional interaction variables: Cueing x Young vs Older Children and Cueing x Older Children vs Adults.

The analysis showed that Model 1 explained 5.8% (Adjusted R^2 = 3.5%) of the variance in distraction ratios but this was non-significant (*F*(3, 125) = 2.55, *p* = .059; *see Table 3.5*). The addition of the interaction terms showed Model 2 to significantly explain 14.6% (Adjusted R^2 = 11.1%) of the variance in distraction ratios (*F*(5, 123) = 4.21, *p* = .001). Model 2 produced a significant change in explaining an additional 8.8% of the variance in distraction ratios, relative to Model 1 (*F*(2, 123) = 6.37, *p* = .002).

Table 3.5. Regression model for predictors of distraction ratios in the Baseline block.

	Model 1 *R^2 = .058*	*Model 2* *R^2 = .146*** *ΔR^2 = .088***
Predictor	*β*	*β*
Cueing	.086	.237*
Young vs Older Children	-.042	-.257*
Older Children vs Adults	.210	.100
Cueing x Young vs Older Children		.531**
Cueing x Older Children vs Adults		.345*

Note: * *p* < .05; ** *p* < .01; *** *p* < .001.

Further assessment shows that the dummy variable Young vs Older Children ($t(123) = -2.07$, $p = .040$) and Cueing ($t(123) = 2.31$, $p = .023$) met significance. The interaction term Cueing x Young vs Older Children also explained a significant proportion of the variance in Model 2 ($t(123) = 3.55$, $p = .001$), as well as Cueing x Older Children vs Adults ($t(123) = 2.02$, $p = .046$). All other predictor variables in Model 2 were non-significant (all *ps* > .05). The interaction terms, Cueing x Young vs Older Children and Cueing x Older Children vs Adults, suggest that the positive relationship of cueing ratio on the amount of distraction experienced is significantly different between age-groups.

To understand the direction of these findings, I used Pearsons' Correlation Coefficients to further explore the relationship between cueing ratios (on singleton-absent trials in the Mostly Predictive block) and distraction ratios (in the Baseline block) for each age-group. This showed that five- to six-year-olds had a positive correlation between cueing ratios and distraction ratios ($r = .40$; *see Figure 3.7A overleaf*). This suggests that larger cueing ratios on singleton-absent trials in the Mostly Predictive block is related to larger distraction in the Baseline block. In contrast, nine- to 11-year-olds ($r = -.09$) and adults ($r = -.07$) both had a weak negative correlation between cueing ratios and distraction ratios, which suggests larger cueing ratios in the Mostly Predictive block is related to less distraction in the Baseline block. The relationship between cueing ratios on singleton-absent trials in the Mostly Predictive block and unstandardised predicted values from Model 2, where the outcome variable is average distraction ratio in the Baseline block, corroborates the above findings (*see Figure 3.7B*).

By observing Figure 3.7A, it is possible that there are some five- to six-year-olds who may be influencing the positive correlation found in this age-group. To assess for outlying participants within each age-group, Mahalonobis Distance was calculated based on the two variables of interest in the hierarchical regression: 1) distraction ratios in the Baseline block and 2) cueing ratios on singleton-absent trials in the Mostly Predictive block. No multivariate outliers were found ($p > .001$). Thus, the positive correlation found between cueing ratios in the Mostly Predictive block (on singleton-absent trials) and distraction ratios in the Baseline block in five- to six-year-olds was not influenced by outliers in this age-group.

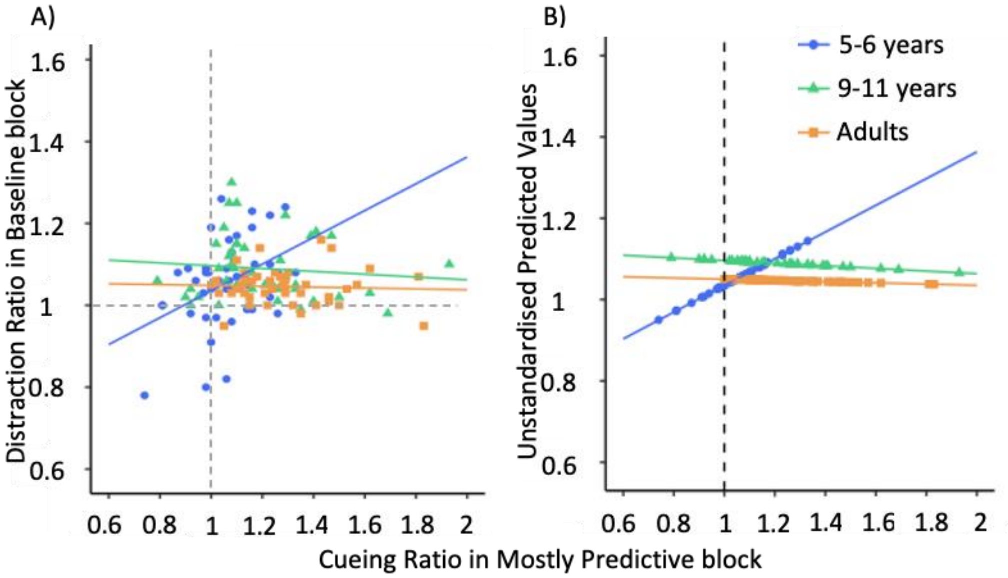

Figure 3.7. The relationship between maintenance and inhibition abilities in the Cued Visual Search task for three age-groups: 5-6 years (blue; *r* = .40), 9-11 years (green; *r* = -.09) and adults (orange; *r* = -.07). This relationship is depicted by A) Pearsons' Correlation Coefficients: cueing ratios on singleton-absent trials in the Mostly Predictive block and distraction ratios in the Baseline block and B) Multiple Regression: unstandardised predicted values from Model 2 and cueing ratios as described above. Linear regression lines are fitted to the data.

Further exploratory analyses were conducted on the dataset to consider 1) block order effects (*see Appendix 3.3*) and 2) Simon effects (*see Appendix 3.4*). The analyses revealed an absence of Simon effects on cue-utilisation and attentional capture. For two (out of six) block orders, order effects influenced attentional capture but not cue-utilisation. In these two orders, participants experienced more distraction on the first block condition they completed relative to the last block condition. However, this finding is not problematic as it 1) was not specific to one type of block condition, 2) affected all age-groups and 3) is a common finding in attentional capture research (Liesefeld et al., 2017).

Discussion

I aimed to understand the development of endogenous control using a Cued Visual Search task. In particular, I investigated the age at which endogenous control is acquired and whether this skill can override or reduce attentional capture caused by a singleton distracter. In this study I found that endogenous cue-utilisation is acquired by mid- childhood. Indeed, cue-utilisation in nine- to 11-year-olds was similar to that of adults, supporting the understanding that by mid-childhood children have developed an “adult-like” endogenous control. In early-childhood however, this study supports research which shows that the period between ages five and six is a key transition period with endogenous control still developing at this stage (Munakata et al., 2012). Contrary to expectation, all age-groups, including adults, were unable to override attentional capture by a singleton distracter with the use of endogenous cues. I also investigated the predictive relationship between the ability to maintain a cue and the ability to inhibit a singleton distracter more generally, when measured independently. The findings suggest that these abilities are only related during early-childhood and may provide evidence for the effects of individual differences during this period. I will discuss each of the findings and their application in turn.

Endogenous control

There is much research which suggests that children aged five to six years have acquired the ability to endogenously control their attention (Jakobsen et al., 2013; Landry et al., 2019; Leclercq & Siéroff, 2013; Hermens, 2018; Wainwright & Bryson, 2005), however others have opposed this (Gaspelin et al., 2015; Johnson et al., 2020). This mixed evidence warranted further investigation. In this study, if participants had developed endogenous control I expected them to show greater cue-utilisation in the Mostly Predictive block as most of the cues in this condition guided their attention towards the target, as opposed to the Low Predictive block (most of the cues guided attention away from the target) and the Baseline block (none of the cues guided attention). Children aged five to six showed no evidence of cue-utilisation in any of the block conditions as cueing ratios did not significantly differ across all three block conditions. The findings support existing research which show endogenous control to have not yet developed or is still developing in early-childhood (Gaspelin et al., 2015; Johnson et al., 2020; Munakata et al., 2012). The inclusion of the Baseline block added further understanding to this field by showing that cueing ratios in the Mostly Predictive block did not significantly differ from baseline performance, where the cues could not guide attention to any item in the search-display. The findings therefore indicate that, overall, five- to six-year-olds were using an exogenous process in all of the block conditions to serially search each individual item until they came across the target (Treisman & Gelade, 1980; Treisman & Sato, 1990). This suggests that five- to six-year-olds were unable to benefit from valid cues in guiding their attention and at the group level, they were not able to maintain the cue to anticipate the upcoming target.

The finding of reduced cue-utilisation in five- to six-year-olds relative to nine- to 11-year-olds appears to conflict with past cueing literature which has indicated that younger children have a larger orienting response than adults (Iarocci et al., 2009; Leclercq & Siéroff, 2013). The measure I used in the analysis of cue-utilisation were cueing ratios (invalid / valid response time) which controlled for differences in baseline response times across age-groups, as opposed to untransformed difference scores (invalid – valid response time) used in past research (Iarocci et al., 2009; Wainwright & Bryson, 2005). I also used a discrimination task rather than a detection task for identifying the target which is known to produce longer response times overall (Ridderinkhof & Van der Stelt, 2000). Some argue that discrimination tasks add an additional process for understanding cue-utilisation at the behavioural level which can cause us to “miss” the phenomena (Johnson et al., 2020; Landry et al., 2019). However, discriminating the target rather than solely detecting it in the Cued Visual Search task was thought to reduce the likelihood of false positive responses which tend to occur more in five- to six-year-olds, relative to adults (Iarocci et al., 2009).

This study indicates that endogenous control is still developing in early-childhood. The next pertinent question concerns whether an “adult-like” endogenous control has been acquired by mid-childhood, or whether this has only developed by late-childhood and adolescence (Goldberg et al., 2001; Leclercq & Siéroff, 2013; Schul et al., 2003; Wong-Kee-You et al., 2019). The findings are consistent with endogenous control being adult-like by mid-childhood (Goldberg et al., 2001; Leclercq & Siéroff, 2013; Iarocci et al., 2009; Pearson & Lane, 1990; Shimi et al., 2014, 2015; Van Gerven et al., 2016). It was found that both nine- to 11-year-olds and adults were able to endogenously orient their attention to locate the target in the Mostly Predictive block. Both age-groups had significantly larger cueing ratios (faster on valid trials vs invalid trials) when the cues usually helped them locate the target.

Overall in this study, cueing ratios in the Mostly Predictive block were significantly larger than cueing ratios in the Low Predictive and Baseline blocks for both nine- to 11-year-olds and adults. This suggests that both age-groups were using more endogenous control in the Mostly Predictive block, relative to the Low Predictive block. The exact processes involved in the Low Predictive block are unclear however. Some research suggests that a Low Predictive block encourages a purely exogenous form of control (Theeuwes et al., 2006; Van der Stigchel et al., 2009) but others propose a hybrid of “endogenous + exogenous” forms of control is used under conditions of highly irrelevant cues (Carlisle & Woodman, 2012; Moher et al., 2014) that can either encourage endogenous control or exogenous control. In the former case, research suggests that cues which infrequently guide attention towards the target discourage cue-utilisation and so any cueing behaviour found in this condition is thought to measure reflexive responses towards the stimuli (Theeuwes, 2013; Theeuwes & van der Burg, 2008; Van der Stigchel et al., 2009).

It is possible, however, that in order to exogenously locate the target, one could utilise a highly irrelevant cue to inform them where *not* to search in the display (Moher & Egeth, 2012; Soto & Humphreys, 2009; Van Gerven et al., 2016). In this instance, participants may strategically create a task-goal to disregard the cued colour in the search-display and instead favour their attention towards the alternative colours (Kiyonaga et al., 2012; Laarni, 2001). Research has shown that when a feature of an irrelevant or distracting item is cued at an early point in processing, this is effective for encouraging participants to endogenously inhibit the distracter-feature in the search-display, which in-turn can allow participants to selectively attend to the target; creating an anti-cue effect (faster on invalid vs neutral trials; Carlisle & Woodman, 2012; Moher et al., 2014; Woodman & Luck, 2007). Interestingly, there is also evidence that items which match highly irrelevant colour cues initially capture attention and are fixated on but later avoided in favour of searching for the target (Beck et al., 2018; Moher & Egeth, 2012). It is possible therefore that nine- to 11-year-olds and adults were using the highly irrelevant cues in the Low Predictive block to strategically search for the target by fixating then avoiding the cued colour. However, both age-groups showed larger cueing ratios in the Low Predictive block relative to the Baseline block and so further evidence would be required to understand the time-course of the "fixate then avoid" strategy using a dot-probe paradigm (Moher & Egeth, 2012). Moreover, as I did not directly assess this question it may be that the possible avoidance of the cued colour was a consequence of selectively attending to it then deploying attention to other items in the display rather than endogenously avoiding the cued colour (Beck et al., 2018).

Nevertheless, regardless of whether individuals use a reflexive exogenous or hybrid of processes in the Low Predictive block, the findings demonstrate that both nine- to 11-year-olds and adults can benefit from valid cues in a highly predictive context, which can encourage them to encode and utilise the cues in order to anticipate the upcoming location of the target before they see it (Carlisle & Woodman, 2011; Goldberg et al., 2001; Leclercq & Siéroff, 2013).

Attentional Capture

One of the key aims of this study was to understand whether utilising an endogenous process would benefit performance by overriding or reducing attentional capture caused by the presence of a singleton distracter. If endogenous control benefited performance in this way, it was expected that participants would show reduced distraction on valid trials in the Mostly Predictive block relative to the Baseline block. The findings showed a non-significant Cue Validity x Block Predictiveness interaction and this interaction also did not significantly interact with Age-Group. The results therefore show that, in general, both children and adults were unable to override distraction caused by the singleton distracter in any of the block conditions. More specifically to my question, distraction ratios on valid trials in the Mostly Predictive block did not significantly differ from the Baseline block for all age-groups. Both five- to six-year-olds and nine- to 11-year-olds had significantly larger distraction ratios than adults, which supports the view that children are more susceptible to distraction than adults (Gaspelin et al., 2015).

Further investigation showed that when the effect of the singleton distracter on performance was isolated in the Baseline block (little to no effect of the cue), distraction ratios were significantly greater than 1 for all age-groups. This suggests that all age-groups experienced a level of attentional capture from the singleton distracter but overall, they were unable to suppress this response using endogenous cue-utilisation. It should be noted that a main effect of Cue Validity did show that participants experienced less distraction on valid trials, relative to invalid trials overall. However, by looking at the means (*see page 77*), this effect may have been driven by differences in assigned trials in the Baseline block. I will discuss and consider this result in more detail in Chapter 4.

With respect to the development of attentional control, the findings demonstrate that, in general, nine- to 11-year-olds and adults were unable to benefit from utilising endogenous control to prevent distraction. This appears to conflict with past research which suggests that endogenous control can suppress attentional capture when it is used at an early point in processing

(Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017; Michael et al., 2013; Sawaki & Luck, 2010). Instead, the results support the notion that endogenous cues which usually guide attention towards the target, are *not* sufficient to override an automatic response towards a singleton distracter (Forster & Lavie, 2008; Iarocci et al., 2009; Theeuwes, 2010; Theeuwes & van der Burg, 2008; Van der Stigchel et al., 2009). I have extended this current understanding from a developmental perspective, by showing that this lack of control over an exogenous response towards a distraction is demonstrated in both adults and children despite both having developed a form of endogenous control (Merrill & Conners, 2013; Iarocci et al., 2009; Rodrigues & Pandeirada, 2018; Theeuwes & van der Burg, 2008; Van der Stigchel et al., 2009; Wong-Kee-You et al., 2019). This therefore suggests that both developing and developed forms of endogenous control encouraged by cue-guidance are unable to override attentional capture, at least in this case.

The current findings oppose the claims made by hybrid accounts of attentional capture and rather could be explained by bottom-up theories. The signal suppression hypothesis suggests that early anticipation for the target or a feature of the target would be effective for suppressing the early “attend to me” signal created by the singleton distracter (Sawaki & Luck, 2010). The findings are not in line with this account, as it was shown that early cue-utilisation for the feature of an upcoming target led to behavioural distraction when the singleton distracter was present relative to absent from the display (singleton presence cost). In contrast to this, the rapid disengagement hypothesis proposes that covert attention (without eye movements) is immediately captured by the most salient item in the search-display but then rapidly disengages in favour of selectively attending to the target (Theeuwes, 2010). This theory suggests that covert attention rejects the singleton distracter before an overt eye movement is made towards the item and as a consequence of this initial capture, participants experience a singleton presence cost on their behavioural (response time, accuracy) responses. Although eye movements were not tracked, the instructions during the practice phase encouraged participants to search around (overt attention) for the target. Nevertheless, the possibility of covert attention cannot be totally ruled out as the tilted line was a singleton item amongst vertical lines and so, it could have been detected without overt eye movements (*see Future Directions for more on this*). It is possible therefore that children and adults in this study were first covertly captured by the singleton distracter, before disengaging and deploying their attention towards the cued colour in the search-display. It should be noted however that this study did not aim to compare attentional capture accounts, as I did not assess whether covert vs overt attention led to capture or whether rapid eye movements were made before deploying attention towards the cued colour (Gaspelin et al., 2017; van Zoest, Donk & Theeuwes, 2004). Therefore additional measures would need to be made to gain further clarity.

Comparing maintenance and inhibition in development

Past research has suggested that maintenance and inhibition abilities are independent but related processes (Berger et al., 2005; Brodeur & Boden, 2000; Corbetta et al., 2000; Kim et al., 1999; Leclercq & Siéroff, 2013; Wainwright & Byson, 2005). These processes are highly regarded in the context of the Cued Visual Search task, as participants are often encouraged to maintain a highly relevant valid cue but they must also inhibit invalidly cued locations. It is unsure whether both of these skills are related (e.g. better maintenance leads to better inhibition ability) and whether this relationship changes in development.

I investigated the relationship between maintenance and inhibition abilities when measured in independent block conditions, to further assess the role of these processes in the control of attentional orienting. I defined maintenance ability as cue-utilisation on singleton-absent trials in the Mostly Predictive block; a context which encouraged early maintenance of the cue for usually guiding attention towards the target. Inhibition ability was defined as the level of distraction caused by the singleton distracter in the Baseline block; a condition which had low cue-guidance and isolated the influence of the singleton distracter on attention and its inhibition. I assessed the relationship between these measures and whether age moderated this relationship. I expected to find a negative relationship, such that as the ability to maintain a cue increases, distraction caused by the singleton distracter decreases. The model significantly predicted 14.6% (Adjusted R^2= 11.1%) of the variance in distraction ratios. Specifically, this showed that the relationship between maintenance and inhibition abilities in the Cued Visual Search task changed with age; in particular, it changed between ages six and nine but only marginally changed between nine and adulthood. At an early age both of the skills are related, but they are no longer related during mid-childhood and adulthood. A closer inspection of the relationship shows us that, in contrast to the predictions, increased ability to maintain cues in the five- to six-year-olds was moderately correlated with increased distraction caused by the singleton distracter.

This is not the first study to find that better maintenance ability is linked to poorer inhibition ability in five- to six-year-olds. Previous research has suggested that large orienting responses (fast valid vs slow invalid) found in five- to six-year-olds, is suggestive of their capability to maintain the cue to guide their attention but it also suggests that they are less capable of inhibiting invalidly cued locations (Brodeur & Boden, 2000; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005). Despite not finding significant levels of cue-utilisation in five- to six-year-olds at the group level, the moderation analyses allowed us to inspect the independent skills at the individual level within each age-group. It is shown that some individuals within the five- to six-year-old age-group have better maintenance ability but this maybe at a consequence of poorer inhibition ability. Therefore, it is possible that “good maintaining, but poor inhibition”, may not apply to all five- to six-year-olds as suggested by others (Brodeur & Boden, 2000; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005). Rather the results offer support for individual differences in maintenance ability, as suggested by similar findings with different experimental paradigms (AX-Continuous Performance Task: Gonthier et al., 2019; Dimensional Change Card Sort: Marcovitch, Boseovski, Knapp & Kane, 2010; Blackwell & Munakata, 2014). Indeed, the period between ages five and six is highly regarded as a key transition period for the development of maintenance ability and endogenous control (Munakata et al., 2012; Lucenet & Blaye, 2014). This study suggests that it is those individuals who have started to develop maintenance ability within this period, who have poorer associated inhibition ability.

A possible consequence of individual differences in maintenance ability in early-childhood has been shown in a study conducted by Blackwell and Munakata (2014). They asked six-year-olds to perform two different tasks. In the first, children were required to switch between rules when sorting cards in the 3-Dimensional Change Card Sort task. In the second, children needed to maintain an image which disappeared and select the matching image after a delay period in the delayed match-to-sample task. The findings showed that some six-year-olds were able to switch between task rules (switchers) and some could not (perseverators). Importantly, the "switchers" experienced greater distraction from a secondary motor task (finger tapping) during the delay period of the delayed match-to-sample task, relative to perseverators. They concluded that children whose maintenance ability have started to improve in this age-group are more likely to attempt to maintain early information when they are encouraged. However, when the cognitive load of a task is increased (e.g. maintaining a secondary task or task-goal), their limited cognitive capacities are insufficient for completing the task. They further reasoned that "switchers" may have attempted to maintain early information but when this was too demanding on their limited resources, this may have resulted in them changing strategies to an exogenous or *reactive* form of control (Blackwell & Munakata, 2014; Blackwell, Chatham, Wiseheart & Munakata, 2014). A similar pattern may have occurred in my study, whereby some five- to six-year-olds may have better maintenance ability than others of the same age but this may have come at a consequence on their limited cognitive capacities; leading these individuals to experience greater distraction from the singleton distracter.

Consistent with this line of reasoning, it may be that the five- to six-year-olds were attempting to maintain a task-goal in the Baseline block. As mentioned in my earlier discussion, some have argued that a block which contains a majority of invalid (or neutral) cues creates a context which encourages avoidance of the cued information (Beck et al., 2018; Moher & Egeth, 2012; Woodman & Luck, 2007). Under this latter context, it is argued that endogenous control is strategically used to create an implicit task-goal (i.e. ignore the cued colour), to help participants to avoid the cued item in the search-display and selectively search for the target in the un-cued locations (Moher & Egeth, 2012). In the Low Predictive block and more specifically, the Baseline block, participants may have been maintaining a task-goal to avoid or ignore the information from the cue. It may be that the five- to six-year-olds with better maintenance ability in the Mostly Predictive block, also attempted to maintain an early task-goal to inhibit the cued information in the Baseline block. As a result, this may have increased the cognitive load of the task. As cognitive resources are being used to actively maintain early information and by doing so, draining the limited capacities that are available, it may have made these individuals vulnerable to interference from the singleton distracter (Blackwell & Munakata, 2014; Lavie, Hirst, de Fockert & Viding, 2004). This provides greater clarity on this finding, as it suggests that although maintenance ability is improving during ages five and six, this may come at a cost under situations where cognitive load is high; making children susceptible to distraction.

One could argue that neutral trials in the Baseline block would not encourage participants to ignore the cue: Neutral cues which do not match any item in the search-display may not offer enough incentive for participants to disregard the cue for impinging on their performance (as the Low Predictive block might). At the same time, it is important to note that the practice phases may have encouraged participants to ignore the irrelevant cues. The practice of trials in the Baseline block (and Low Predictive block), allowed participants to learn about the irrelevance of the cues and they were made aware of this when they were asked whether Dory's clues were helpful or not. This may have led them to acquire an implicit task-goal to ignore the unhelpful clues. Past evidence has shown that both explicit and implicit task-goals has discouraged cue-utilisation in adults (Carlisle & Woodman, 2011; Woodman & Luck, 2007) and children (Leclercq & Siéroff, 2013; Van Gerven et al., 2016). Therefore, there may have been a basis for actively ignoring the neutral cues in the Baseline block.

Later in development, nine- to 11-year-olds and adults' maintenance and inhibition abilities, as measured independently in the Cued Visual Search task, were not related to one another. Previous research has suggested that these abilities are key components of attentional orienting (Brodeur & Boden, 2000; Wainwright & Bryson, 2005). Due to this understanding, it was expected that better maintenance ability would be associated with better inhibition ability, particularly in those who have developed endogenous control. However, it was showed that nine- to 11-year-olds and adults behaved similarly as both of these age-groups showed weak negative relationships between these two skills. Others have found similar results using the Cued Visual Search task, as target-enhancement and distracter-inhibition was weakly associated in young adults (Noonan et al., 2016). They compared cueing effects when the target location was cued with cueing effects when the distracter location was cued. They concluded that facilitating the signal for the target differs from active inhibition of a distracter signal. This suggests that these skills have distinctive mechanisms from one another which was further exemplified at the neural level, as target cues led to early alpha-band oscillations (signal of inhibition gating mechanism; Jensen & Mazaheri, 2010), but, despite predictions, this was not shown for distracter cues. Arguably, predictive cues require maintenance to establish endogenous cueing effects, irrespective of whether they cue the target or the distracter and therefore it is difficult to make comparisons between the studies (Chelazzi et al., 2019). Nevertheless, the findings from the current chapter add to the existing field by showing that maintenance and inhibition processes may become independent processes from mid-childhood when an adult-like endogenous form of control has developed. This could potentially explain the inability for nine- to 11-year-olds and adults to utilise endogenous cues to reduce attentional capture.

Future Directions

The initial analysis which assessed the relationship between the ability to maintain a cue and the ability to ignore the singleton distracter *within each block condition*, contrast with the findings from the multiple linear regression analysis (interpreted above) which compared these abilities in *independent block conditions*. To reiterate, the regression showed age moderated this relationship, specifically, a positive relationship between cueing ratios in the Mostly Predictive block on singleton-absent trials and distraction ratios in the Baseline block was found for five- to six-year-olds. In contrast, a weak negative relationship between these two skills were found in nine- to 11-year-olds and adults. In contrast to this, the relationship between these skills within each block condition show all age-groups to have a positive relationship (better cueing, more distraction) to some extent *within* the Mostly Predictive block and the Baseline block but a negative relationship (better cueing, less distraction) in the Low Predictive block. This suggests that in all age-groups there is some level of trade-off between the ability to maintain a cue and the ability to inhibit a singleton distracter, which may indicate a limit on cognitive performance throughout childhood and young adulthood. However it is important to note that this conclusion does not agree with the results of the more methodologically rigorous multiple regression analysis and therefore, the conclusions drawn here are cautious and warrant further investigation. This finding will be reviewed in Chapter 4 with regards to the positive correlation found in the Baseline block, as well as considered in future chapters.

With respect to the task itself, it should be noted that in my variant of the Cued Visual Search task, the predictability of the cue in the Mostly Predictive block (66.67% valid) may not have been high enough to encourage young children to maintain the cue. Past research has manipulated block predictability by ensuring the cue is valid on 80-100% of trials in a block condition, which has reliably encouraged cue-utilisation in both children and adults (Berger et al., 2005; Leclercq & Siéroff, 2013; Noonan et al., 2016; Theeuwes & van der Burg, 2008; Wainwright & Bryson, 2005). Much research has considered the role of stimulus onset asynchronies of cue presentation on this skill (Brodeur & Boden, 2000; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005) but future research would benefit from considering the influence of block predictability on cue-utilisation in childhood, as this manipulation is vital for creating a context to encourage cue-use and form an implicit task-goal (Carlisle & Woodman, 2011; Jonides, 1981; Soto et al., 2008). I investigate the influence of block predictiveness levels on cue-utilisation in children in Chapter 5.

Much of the research I have discussed in relation to the findings thus far has considered the development of higher-order processes during key periods of childhood. A large body of evidence in the cognitive control literature has also considered similar questions to this study using different behavioural paradigms. The findings of the present study are consistent with a developmental shift from reactive to proactive control. As mentioned in Chapter 1, the Dual Mechanisms of Control theory proposed by Braver (2012) argues that attention can be controlled in two ways. Proactive control is similar to our understanding of endogenous control, as this strategy is theorised to encourage maintenance of task-goals in working memory to enable anticipation for an upcoming event at an early point of processing. Reactive control is similar to exogenous control as it stipulates that early maintenance of a task-goal is not required but rather it reactivates this goal in-the-moment that it is required. There is much research which has investigated the development of proactive control and in particular the transition from mainly using a reactive strategy to mainly using a proactive strategy (Ambrosi, Lemaire & Blaye, 2016; Chatham et al., 2009; Chevalier et al., 2015, 2020; Lorsbach & Reimer, 2008, 2011; Lucenet & Blaye, 2014, 2019). This study contributes towards this literature, as the manipulation of block predictability created a context which aimed to encourage participants to form an implicit task-goal to attend and maintain the largely helpful cues in the Mostly Predictive block; suggestive of encouraging proactive control (Leclercq & Siéroff, 2013; Brodeur & Boden, 2000). In the Low Predictive and Baseline blocks however, this produced a context which discouraged cue-maintenance as cues were shown as redundant for locating the target and so ignoring of the cue may have allowed participants to serially search for the target; this is suggestive of reactive control. Overall, the findings indicate that five- to six-year-olds are still mostly dependent on utilising a reactive form of control, whereas nine- to 11-year-olds and adults benefit from their use of proactive control for attentional orienting (Lorsbach & Reimer, 2011; Lucenet & Blaye, 2014). Further investigation should aim to compare the Cued Visual Search task with another well-known measure of proactive control such as the AX-Continuous Performance Task (AX-CPT) which also manipulates contextual information to assess whether participants can utilise early task-goals (Braver, 2012; Redick, 2014) in order to directly facilitate comparisons between the two literatures. I consider this question in relation to aging effects from young to older adulthood in Chapter 6.

One potential cause for the lack of endogenous control over attentional capture in this study could be due to the nature of the visual search task. My target item by definition was a singleton item in the search-display, as participants searched for a white tilted line presented amongst two white vertical lines. It is argued that a target which is a singleton in the search-display may encourage participants to utilise a singleton detection mode (Bacon & Egeth, 1994; Lamy et al., 2004; Leber & Egeth, 2006). This strategy enables users to search for the “odd item” in the display. When a target item is a singleton in the search-display, adults experience attentional capture by a singleton distracter but this response is suppressed when the target item is not a singleton (Gaspelin et al., 2015, 2017; Sawaki & Luck, 2010, 2013). Here, a singleton detection mode may have made participants more vulnerable to distraction by a unique distracter item. I further explore the relationship between the target and the distracter on endogenous cue-utilisation and capture in Chapter 7.

Conclusion

In the present study I investigated the development of endogenous control from early-childhood to adulthood and assessed whether endogenous control benefits children and adults by overriding attentional capture. I found that endogenous control is still developing in early-childhood. This suggests that even when encouraged by cues which are usually predictive of the target's location, five- to six-year-olds as a group tended to mostly utilise an exogenous form of control to search for the target (Gaspelin et al., 2015; Johnson et al., 2020; Munakata et al., 2012). Nine- to 11-year-olds behaved similarly to adults as both age-groups utilised an endogenous process in a high predictive context (Goldberg et al., 2001; Leclercq & Siéroff, 2013). However, all age-groups were unable to override attentional capture in the Mostly Predictive block, supporting the understanding that endogenous cues may not be sufficient to reduce distraction in both children and adults (Beck et al., 2018; Moher & Egeth, 2012; Theeuwes, 2010; Theeuwes & van der Burg, 2008; Van der Stigchel et al., 2009). The findings also agree with the notion that five to six years is a key transition period for attentional control, as the results provide evidence of possible individual differences in maintenance ability which may be associated with poorer inhibition skill. By mid-childhood however, maintenance and inhibition abilities grow to become independent skills used in attentional orienting. Future research should further assess the role of context and the relation between the target and distracters to consider how we can encourage endogenous control across development as well as reduce the likelihood of attentional capture.

Chapter 4: Cross-Colour Priming Effects in the Baseline Block

Abstract

There were two unexpected results in Chapter 3 concerning the Baseline block. First, a main effect of Cue Validity showed participants experienced less distraction on valid vs invalid trials overall. Second, larger "cueing" ratios in Baseline was positively related to larger distraction ratios in this condition. The cue included on neutral trials in the Baseline block was not expected to guide attention, as the cued colour was absent from the search-display. Trials in the Baseline block were assigned "valid" and "invalid" variables to make comparisons between the conditions. The unexpected pattern of results might be suggestive of differences between these assigned trials. The current chapter considered the role of cross-colour priming effects in the Baseline block, whereby some cue colours may have primed attention towards different colours in the search-display. In particular, I assessed whether there was cross-colour priming on certain cue-target pairs (e.g. green cue, blue target) and if these pairs occurred more often on trials assigned as "valid" relative to "invalid". The results rejected the predictions. It was shown that any cross-colour priming effects in Chapter 3, were not related to the variable assignment in the Baseline block. Rather participants tended to generally respond faster to targets presented in pink and blue circles. The findings strengthen the claims that show the differences found in cue-utilisation in Chapter 3, were due to endogenous cue-utilisation in the Mostly Predictive block relative to the Baseline block.

Introduction

The findings from Chapter 3 shed some light on some discrepancies in the Baseline block of the Cued Visual Search task. The assignment of "valid" and "invalid" variables in this condition was matched to the Mostly Predictive block. This was because 1) the elements in the search-display between block conditions were kept constant (only differed in terms of cue colour) and 2) the aim concerning attentional capture prevention predicted differences in distraction between the Mostly Predictive and the Baseline block. The results showed two abnormalities. First, the analysis of attentional capture showed a significant main effect of Cue Validity (p = .046) showing distraction ratios, across all block conditions in general, were smaller on valid relative to invalid trials. Closer inspection of the means (*see page 77, Figure 3.4*) suggest that this result might have been driven by assigned trials in the Baseline block. Second, a positive correlation between cueing ratios (in trials assigned as "valid" and "invalid") and distraction ratios (*see page 80, Figure 3.5*) was found in the Baseline block for adults (r = .687, p < .001). This suggests that higher levels of "cue-utilisation" from assigned trials in the Baseline block was associated with higher levels of attentional capture caused by the singleton distracter within the same block. The cue never matched a colour in the search-display of the Baseline block and so it was assumed that the cue information would not guide attention (Soto et al., 2008). I assessed whether Simon effects were greater in the Baseline block relative to the other block conditions (*see Appendix 3.*4) but this was not found. The current analytical chapter aims to explore and attain further clarification for the Baseline findings.

There is an intuitive understanding that colour cues act at the global level to enhance the visual response for matching colours across the entire visual field (Andersen et al., 2011; Laarni, 2001; Motter, 1994). Preferential responses to colours which appear similar or are less discriminable from the cued colour may also be enhanced (Liu, 2019). In a study using a Cued Visual Search task similar to the task in Chapter 3, participants were provided with a memory item following cue presentation on a subset of trials (Kiyonaga et al., 2012). The memory item would either match the colour of the cue or have a similar hue. They found that participants' speed to recognise whether the memory item matched or did not match the cue was influenced by block predictiveness. Specifically, participants were slowest in the 100% invalid block, and fastest in the 100% valid block, relative to neutral trials. This study did not explicitly assess whether recognition was better for the memory item which matched the cue relative to those which were similar in hue. However, the findings do suggest that maintenance of a cued colour can enhance responses to colours which are close in colour proximity.

In the Baseline block, it was expected that a cue which is absent from the search-display would not guide attention (Soto et al., 2008), but this might be influenced by colour proximity. Research has shown that when the target's colour is in close proximity in colour space to the cue, visual evoked potentials for this target are increased (Martinovic, Wuerger, Hillyard, Mueller & Andersen, 2018). It has been reasoned that enhancement of colour signals can encompass colours which are in close proximity to one another in the colour space; making the appearance of these colours at the behavioural level to be less discriminable from one another (Pestilli, Carrasco, Heeger & Gardner, 2011). The feature-gain similarity model reasons that *cross-colour priming effects* may arise from the systematic modulation of preferential neural responses by an attended feature or cue (for a review, see Liu, 2019). Indeed, performance is slower or less accurate when discriminating between colours within the same category, relative to colours between categories (Bornstein & Korda, 1984; Franklin et al., 2005; Pilling, Wiggett, Özgen & Davies, 2003). This is a finding commonly found in both adults and children (Franklin & Davies, 2004; Franklin et al., 2005). Therefore, the relationship between the colour of the cue and the colour of the circle which contained the target might have influenced performance in the Baseline block.

To revisit my earlier discussion, Chapter 3 showed that all participants experienced less distraction on valid trials than invalid trials across all block conditions (main effect of Cue Validity on distraction ratios). The means might suggest that this effect was driven by differences between assigned "valid" and "invalid" trials in the Baseline block (*see page 77, Figure 3.4*). Moreover, in adults, higher levels of "cue-utilisation" from assigned trials in the Baseline block was positively associated with higher levels of attentional capture (*see page 80, Figure 3.5)*. In relation to the findings, it is possible that cross-colour priming effects may have occurred in the Baseline block. In particular, cross-colour priming would be defined as faster response times on trials where the colour of the cue is similar to that of the target. If more of these trials were assigned as “valid” relative to “invalid” in the Baseline block, this might explain the differences found between these trials. The current analytical chapter will consider whether the aforementioned findings in the Baseline block were the result of cross-colour priming effects. Specifically, I will assess whether there are more trials, which had cross-colour priming, that were assigned as “valid” compared to “invalid” in the Baseline block.

The aims of this chapter were to understand 1) if cross-colour priming effects occurred on certain trials and 2) if this occurred more often in trials assigned as “valid” compared to “invalid” in the Baseline block, explaining the unexpected pattern of findings in Chapter 3. To specify, I wanted to explore whether there were more cue-target colour pairs which caused fast response times (priming effects) than I expected. In particular, it would be insightful to assess whether I observed more fast cue-target pairs that were assigned as “valid”, as well as fewer fast cue-target pairs that were assigned as “invalid” than I expected. This will allow me to relate any possible priming effects in the Baseline block (fast vs slow response times) to my variable assignment (valid vs invalid). It was predicted that if there are cross-colour priming effects in the Baseline block, I would observe more cue-target pairs than I expected that were coded as “valid” and led to fast response times. I also predicted that I would observe more cue-target pairs than I expected that were coded as “invalid” and led to slow response times.

Analysis

To assess the predictions, I used a Chi-Squared Goodness of Fit to understand whether the observed frequencies of certain cue-target pairs were fewer or greater than expected. This non-parametric analysis is optimal for the question as it allows us to compare whether the observed distribution of cue-target count data follows the expected probability distribution (Lancaster & Seneta, 2005). The analysis was conducted using adult data[9] on

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[9] Both discrepancies found in the Baseline block were shown in adults and so this warrants any further assessment of these results to be explored within this age-group.

singleton-absent trials to remove the influence of the singleton distracter, which is known to affect response times. If priming effects were found on singleton-absent trials, it was likely to also transpire on singleton-present trials.

In the Baseline block, there were 12 different cue-target colour pairs (Blue-yellow, Blue-green, Blue-pink, Green-yellow, Green-blue, Green-pink, Yellow-blue, Yellow-green, Yellow-pink, Pink-yellow, Pink-green, Pink-blue). It is agreed that green, blue and yellow are defined as primary unique hues and pink is a secondary hue which is part of the red hue family (Franklin et al., 2005). Pink (or red) and blue have been used to investigate priming effects as they are often classed as being closer in the colour space, with purple acting as their intermediate (Martinovic et al., 2018; Wuerger, 2013). It should be noted however, discriminability between colours can be adaptive and is subject to the physical properties of the colour stimuli included in the study (Liu, 2019; Martinovic et al., 2018). The colours chosen for the Cued Visual Search task aimed to ensure that they were distinguishable from one another. Due to this, an exploratory approach was used to assess which cue colours would prime other colours in the search-display. It was expected that the cue-target pairs with the fastest average response times in the Baseline block were likely to represent the pairs which caused (the most) priming effects in this condition. Using this criteria, all further analysis was conducted on the fastest six cue-target pairs (*see Figure 4.1*).

I conducted a median split on response times based on data[10] from singleton-absent trials across all adult participants. Response times faster than the median are now referred to as “fast response times” and those slower than the median are now referred to as “slow response times”. The observed frequencies for the cue-target pairs were counted based on fast vs slow response times and “valid” vs “invalid” assigned trials. The expected frequencies for each cue-target pair were calculated based on the variable assignment of these trials used in Chapter 3.

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[10] The response time data used in this analysis had been filtered following the same procedure discussed in Chapter 3.

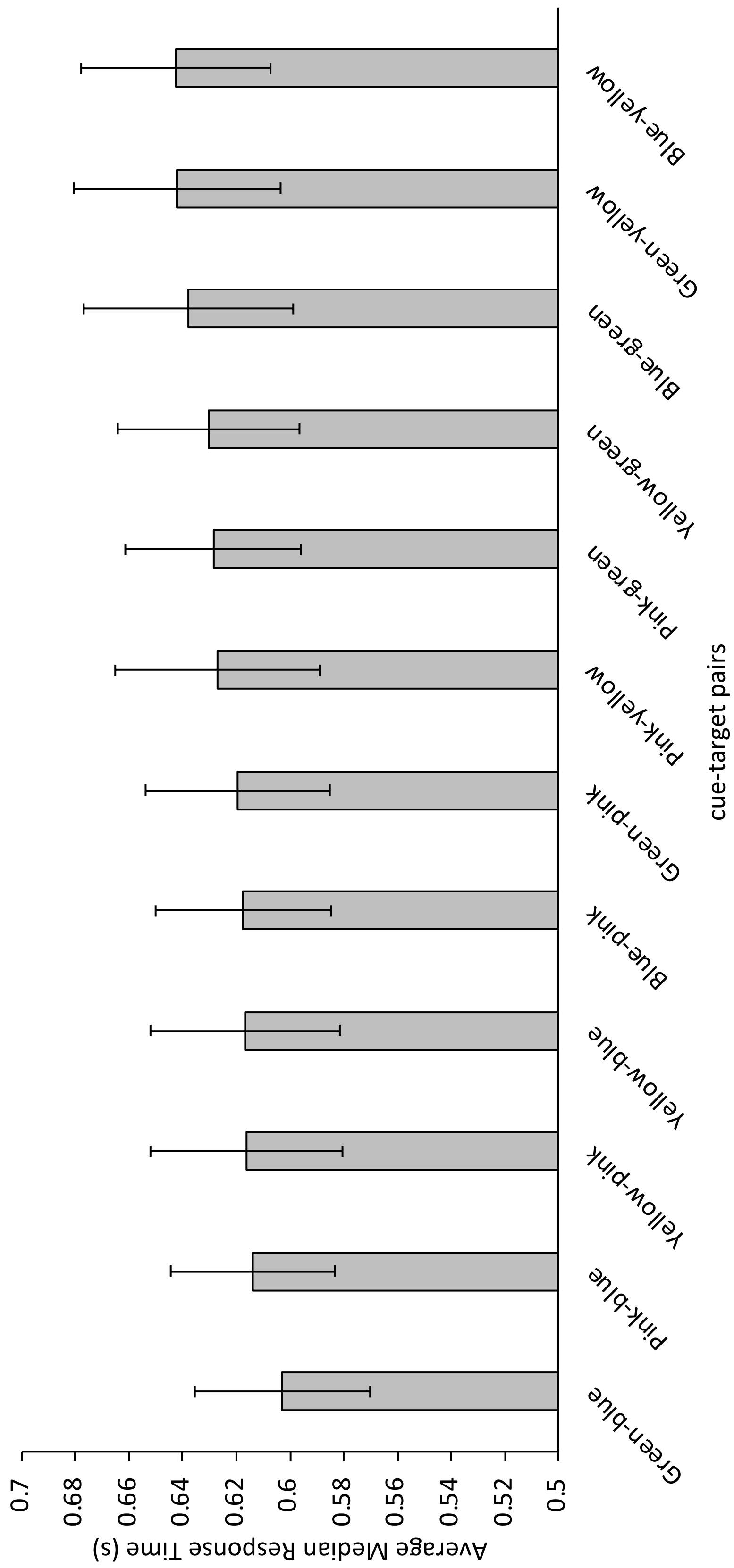

Figure 4.1. Average median response times (s) for cue-target colour pairs on singleton-absent trials in the Baseline block for adults. Error bars represent 95% confidence intervals.

As shown in *Table 4.1* (*see overleaf*), the assignment of cue-target pairs was unevenly assigned as “valid” and “invalid” trials. For instance, yellow-pink and blue-green cue-target trials were never assigned as “invalid” trials. It is important to note that in the Baseline block, cue-target pairs were equally represented *overall*[11]. The assignment of “valid” and “invalid” variables in Chapter 3 was based on the Mostly Predictive block, where the counterbalancing of the cue-target pairs within this block ensured that they were equally distributed amongst trial types to control for learning associations. As the colour of the cues differed between block conditions, this meant that the proportions of cue-target pairs were unequally represented between “valid” and “invalid” assigned trials within the Baseline block. To acknowledge this, I calculated the expected frequencies for each cue-target pair based on the proportions highlighted in *Table 4.1*.

Results

Chi-Squared Goodness of Fit was calculated using *Equation 4.1* which assessed whether there was a significant difference between the observed and expected frequency distribution.

Equation 4.1

$$X^2 = \sum \frac{(O - E)^2}{E}$$

Where O is the observed value and E is the expected value, whereby the sum of squared differences between these values was calculated to attain the Chi-Squared statistic.

This statistic was compared to a critical value attained from a Chi-Square distribution when the alpha criterion was .05 and the degrees of freedom was the number of categories (cue-target pairs) – 1, which was 5.

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[11] With the exception of the slight imbalance in proportion between yellow-blue and pink-blue cue-target pairs which differed by one trial. This imbalance was also replicated in the Mostly Predictive block.

Table 4.1. Proportion of cue-target singleton-absent trials coded as "valid" and "invalid" in variable assignment.

"Valid" Assigned Trials

		Target Circle Colour			
		yellow	*pink*	*blue*	*green*
Cue Colour	*Yellow*		8.33%	4.76%	4.76%
	Pink	7.14%		8.33%	5.95%
	Blue	7.14%	4.76%		8.33%
	Green	5.95%	5.95%	7.14%	

"Invalid" Assigned Trials

		Target Circle Colour			
		yellow	*pink*	*blue*	*green*
Cue Colour	*Yellow*		0.00%	2.38%	3.57%
	Pink	1.19%		1.19%	2.38%
	Blue	1.19%	3.57%		0.00%
	Green	2.38%	2.38%	1.19%	

All Trials

		Target Circle Colour			
		yellow	*pink*	*blue*	*green*
Cue Colour	*Yellow*		8.33%	7.14%	8.33%
	Pink	8.33%		9.52%	8.33%
	Blue	8.33%	8.33%		8.33%
	Green	8.33%	8.33%	8.33%	

Separate Chi-Squared Goodness of Fit analyses were conducted on assigned "valid" and "invalid" trials[12] for fast and slow response times to assess if cross-colour priming effects were present and whether they were related to the variable assignment in the Baseline block. Cross-colour priming effects were defined as resulting in fast response times on the six chosen cue-target pairs. It was predicted that cross-colour priming effects would be found more frequently in trials assigned as "valid" and less frequently in trials assigned as "invalid" to explain the unexpected pattern of results in Chapter

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[12] Yellow-pink trials were not included in the analysis of "invalid" assigned trials as variable assignment meant that I did not expect any of these trials to be coded as "invalid" in the Baseline block. The degrees of freedom and critical value for this analysis were adjusted to account for this.

3. This would be shown by cue-target pairs which led to fast response times, occurring more often in assigned “valid” trials and less often in assigned “invalid” trials than it was expected. The opposite pattern of results is expected to occur for slow response times. Whereby, cue-target pairs which led to slow response times would occur less often in “valid” assigned trials but more often in “invalid” assigned trials than expected.

Fast Response Times

The results showed that there was no significant difference between observed and expected frequencies for “valid” assigned trials ($X^2(5) = 2.73$, $p > .05$; critical value = 11.07; *see Table 4.2 overleaf-top*). However, a significant difference was found between observed and expected frequencies for “invalid” assigned trials ($X^2(4) = 16.30$, $p < .05$; critical value = 9.49; *see Table 4.3*). The direction of this effect opposes the prediction as it showed that cue-target pairs which led to fast response times were observed more frequently in assigned “invalid” trials than it was expected.

Slow Response Times

No significant difference between observed and expected values for “valid” assigned trials was found ($X^2(5) = 2.92$, $p > .05$; critical value = 11.07; *see Table 4.3 overleaf-bottom*). For “invalid” assigned trials, a significant difference was found between observed and expected frequencies ($X^2(4) = 10.42$, $p < .05$; critical value = 9.49; *see Table 4.4*). The direction of this result showed that cue-target pairs which led to slow response times, were observed less frequently in assigned “invalid” trials than expected which opposes the aforementioned prediction that expected more would be observed.

Overall, the results show that the cue-target pairs which led to fast response times, were observed more than expected in trials assigned as “invalid” in the Baseline block. At the same time, the opposite was shown for cue-target pairs which led to slow response times (fewer than expected for trials coded as “invalid”). No differences were found between observed and expected frequencies in trials assigned as “valid”.

Table 4.2. Observed and Expected frequencies for ***fast*** Cue-target trials weighted by “Valid” and “Invalid” variable assignment.

	Assigned “Valid” Trials		**Assigned “Invalid” Trials**	
	Observed	*Expected*	*Observed*	*Expected*
Green-blue	262	240	48	40
Pink-blue	274	280	49	40
Yellow-pink	287	280	0	0
Yellow-blue	163	160	95	80
Blue-pink	154	160	133	120
Green-pink	195	200	106	80

Table 4.3. Observed and Expected frequencies for ***slow*** Cue-target trials weighted by “Valid” and “Invalid” variable assignment.

	Assigned “Valid” Trials		**Assigned “Invalid” Trials**	
	Observed	*Expected*	*Observed*	*Expected*
Green-blue	219	240	35	40
Pink-blue	278	280	33	40
Yellow-pink	275	280	0	0
Yellow-blue	155	160	69	80
Blue-pink	169	160	109	120
Green-pink	208	200	58	80

Discussion

The current analytical chapter aimed to assess whether there were cross-colour priming effects in the Baseline block to ascertain if this could explain the discrepancies found in this condition in Chapter 3. I explored whether there were more cue-target trials of a particular colour pairing than expected based on the variable assignment of “valid” and “invalid” trials in the Baseline block. In particular, I assessed whether cross-colour priming was present in certain colour pairings and if these trials were disproportionately represented in “valid” and “invalid” assigned trials, explaining the unexpected findings in Chapter 3. It was predicted that cue-target pairs which resulted in fast response times, would be observed more frequently than expected in trials assigned as “valid”. In contrast, cue-target pairs which resulted in slow response times would be observed more frequently in “invalid” assigned trials than it was expected. The results oppose the predictions as no differences were found between observed and expected frequencies for assigned “valid” cue-target pairs which resulted in fast or slow response times. Significant differences between the distribution of observed and expected frequencies were found for “invalid” assigned trials but in the opposite direction than was predicted. In general, the findings showed that adults had a preference for responding faster to targets located within pink and blue circles in the search-display. When these trials were coded as “invalid” they were observed more than expected as trials which led to fast response times and less so as trials which led to slow response times.

The findings demonstrate that any correspondence between cross-colour priming effects in the Baseline block and variable assignment in this condition was lacking. It is possible that participants had a general preference for responding to targets located within blue and pink circles. But it is important to note that the proportion of colours associated with the target was equally distributed *overall* within the Baseline (and Mostly Predictive) block. Due to this, similar cross-colour priming effects which occur in the Baseline block should also be consistent in the Mostly Predictive block. Therefore, the differences in levels of cue-utilisation found between the

Mostly Predictive block and the Baseline block in adults and nine- to 11-year-olds, can be attributed to endogenous cueing effects in the Mostly Predictive block. Whereby, early maintenance of a cue which guided attention to a matching colour in the search-display is heightened in the Mostly Predictive block.

Future Directions

Despite the lack of cross-colour priming effects shown, the analysis was conducted post-hoc and so this question does warrant further investigation. This would also allow us to investigate whether the discrepancies found in the Baseline block are replicated. Cross-colour priming effects may be influenced by individual differences in the ability to discriminate between categorical colours (Pestilli, Carrasco, Heeger & Gardner, 2011). I further assess this claim in Chapter 6 using an alternative forced choice task (Franklin et al., 2005) to measure colour discriminability to understand if this can account for cueing effects in the Cued Visual Search task.

An alternative line of reasoning for the variability found in the Baseline block may be associated with the singleton distracter. The distance between the target and the singleton distracter is known to influence attentional guidance, with shorter distances leading to attentional capture (attentional window hypothesis; Theeuwes, 2010) or surround suppression effects for an adjacent item (Tsotsos, 1995). This was assessed in Chapter 2 to understand whether trials which presented the singleton distracter in the same quadrant as the target (relative to a different quadrant), influenced performance. This showed better accuracy (no effect on response time) for responding to the target on same-quadrant trials, relative to different-quadrant trials. To understand performance in the different-quadrant trials, this measurement can be further refined by calculating the distance between the target and the singleton distracter. The randomly selected locations for the target and the singleton distracter were not recorded in Chapter 3, but Chapter 7 further assesses this effect.

Chapter 5: The Influence of Block Predictiveness on Endogenous Cue-Utilisation in Early- and Mid-Childhood

Abstract

There is mixed evidence regarding the development of endogenous control in the Cued Visual Search task. Research has argued that by early-childhood (5-6 years), children are able to maintain early cue information to endogenously orient their attention (Jakobsen et al., 2013; Leclercq & Siéroff, 2013), however this was contested in Chapter 3. In the current chapter, I aimed to investigate whether the predictiveness of the block condition influenced cue-utilisation without the presence of a singleton distracter. Two age-groups (5-6, 9-11 years) were invited to complete three block conditions of the Cued Visual Search task: 1) Mostly Predictive block (66.67% valid, 33.33% invalid trials), 2) Baseline block (100% neutral trials) and 3) the new Always Predictive block (100% valid trials). No singleton distracter was included in the block conditions in the current chapter. The findings showed that there were no age differences found in cue-utilisation. Specifically, both five- to six-year-olds' and nine- to 11-year-olds' performance benefited from valid cues in the Always Predictive block, relative to the Baseline block. They also experienced a cognitive cost on performance when presented with invalid cues in the Mostly Predictive block, compared to Baseline. Cue-utilisation at the block level showed participants had higher cue-use in the Mostly Predictive overall, relative to the Baseline block. Altogether, the findings suggest that a basic form of endogenous control has developed by early-childhood and stays relatively stable until mid-childhood. The possible reasonings and limitations in relation to Chapter 3 will be discussed in turn.

Introduction

An overarching theme of this thesis is to understand and track the development of endogenous control; the skill which can allow us to maintain early cues to guide attention. In Chapter 3, I aimed to investigate this question by manipulating the predictiveness of the cues in three conditions of the Cued

Visual Search task. The findings suggest that endogenous cue-utilisation is still developing in early-childhood: Five- to six-year-olds' cueing ratios did not differ across all conditions, specifically, cueing ratios when the cues were mostly predictive of the target, did not significantly differ from baseline when the cues were never predictive of the target. This could suggest that even when children had incentive to maintain the predictive cues, they were unable to sustain this at the block level. It is important to note that individual differences in cueing ratios showed that some five- to six-year-olds were better at maintaining mostly predictive cues, but this came at a cost with reduced inhibition of the singleton distracter. Therefore, it is possible that overall children aged five to six may mostly rely on using an exogenous (or reactive) form of control to search for the target in the moment it is displayed, instead of planning ahead (Gaspelin et al., 2015; Johnson et al., 2020; Lewis et al., 2018). But the development of endogenous cue-utilisation is "in transition" in some individuals in this age-group (Munakata et al., 2012).

However, the differences between the method used in Chapter 3 and past research may highlight some important issues which require further investigation. The findings discussed above contrast with previous research that has shown an early form of endogenous cue-utilisation to have developed by age six (Brodeur & Boden, 2000; Iarocci et al., 2009; Jakobsen et al., 2013; Landry et al., 2019; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005). There are a number of methodological differences between studies such as the type of cue (location vs feature), stimulus onset asynchronies and items in the search-display, which make it difficult to draw direct comparisons (Ridderinkhof & van der Stelt, 2000). One common difference between the method used in Chapter 3 and previous research (other than the singleton distracter) is the level of block predictiveness for encouraging cue-utilisation. Thus, it is important to question whether children had enough incentive to encourage them to utilise the cues in the Mostly Predictive block (66.67% valid cues). Next, I discuss the manipulation of block predictiveness in detail to ascertain how this can influence endogenous cue-utilisation in children and to help me select a suitable level to be used in the current chapter.

Manipulation of block predictiveness has been shown to influence endogenous cue-utilisation in adults in the Cued Visual Search task (Carlisle & Woodman, 2011; Kiyonaga et al., 2012; Noonan et al., 2016; Soto & Humphreys, 2007, 2009; Weaver, Paoletti & van Zoest, 2014). A common manipulation in this research has shown that a higher proportion of valid (to invalid) cues in a block condition, leads to enhanced cue-utilisation relative to the baseline block condition. At the same time, endogenous cue-utilisation can be used strategically to rapidly locate the target in contexts where the cue is highly invalid (Carlisle & Woodman, 2011; Kiyonaga et al., 2012; Moher & Egeth, 2012; Woodman & Luck, 2007). It is reasoned that block predictiveness leads to the formation of an implicit task-goal concerning the cue (i.e. pay attention to helpful cues; Olivers, Peters, Houtkamp & Roelfsema, 2011; Soto et al., 2008). This suggests that the relevance of the cue in predicting the target plays a large role in cue-utilisation for guiding attention at an early point in processing.

Under more scrutiny, the level of cue-utilisation has been shown to be dependent on the level of block predictiveness. Carlisle and Woodman (2011) asked adults to complete three block conditions of the Cued Visual Search task (20%, 50% & 80% valid cues). They showed that cue benefits on valid trials (faster than neutral) and cue costs on invalid trials (slower than neutral), were amplified with increasing valid probabilities. This effect was also replicated by Laarni (2001) who showed block predictiveness effects to withstand perceptual load (easy vs difficult target search) manipulations. At more extreme levels, Kiyonaga et al. (2012) showed that cue benefits on valid trials and cue costs on invalid trials were enhanced in the 100% valid block and 100% invalid block conditions respectively, relative to the 50:50% valid:invalid block condition. Taken together, this evidence suggests that cue-utilisation is linked to the learnt relevance of the cue at the block level. Some argue that in low predictive blocks, cue-utilisation is a result of exogenous priming (Theeuwes, 2013) or endogenous control which attenuates cue-guidance (Kiyonaga et al., 2012). Above all, it can be agreed that increases in cue-utilisation for high predictive blocks is a result of endogenous control ensuring that the relevance of the cued item is provided with an increased attentional weight (Soto et al., 2008; Wolfe, 2014). Therefore, in adults, endogenous cue-utilisation can be modulated by block predictiveness levels to create an implicit task-goal.

Block predictiveness has also been shown to modulate cue-utilisation in children. Five- to six-year-olds had higher levels of cue-utilisation in the 80% valid block condition, relative to the 50% valid block and the 80% invalid block conditions (Brodeur & Boden, 2000; Iarocci et al., 2009; Jakobsen et al., 2013; Landry et al., 2019; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2002, 2005). Further inquiry has highlighted that the cueing effects for five- to six-year-olds is largest in the mostly predictive block conditions relative to older age-groups, which may be suggestive of a failure to modulate cue-guidance on invalid trials (i.e. inhibition deficit; Brodeur & Boden, 2000). In later childhood however, nine- to 11-year-olds have better modulation which appears adult-like, as their cue-utilisation is dependent on block predictiveness levels but they are able to control cue-guidance in predictive contexts, compared to unpredictive contexts (Goldberg et al., 2001; Iarocci et al., 2009; Leclercq & Siéroff, 2013; Shimi et al., 2014, 2015; Wainwright & Bryson, 2002, 2005). In general, the evidence suggests that block predictiveness plays an important role in modulating cue-utilisation in early- and mid-childhood.

It is uncertain whether cue-utilisation in children is manipulated by block predictiveness or other methodological factors. In all of the research discussed above, stimulus onset asynchronies were manipulated (except in Shimi et al., 2014, 2015), memory arrays were included to assess working memory questions (Shimi et al., 2014, 2015) or exogenous cues were displayed during endogenous cue maintenance (Iarocci et al., 2009). It is known that longer stimulus onset asynchronies between the cue and the target displays, lead to greater cue-utilisation as this interval ensures there is more time to encode, maintain and prepare to make an anticipatory response to the cued item (Adams & Chambers, 2012; Jiang, Sigstad & Swallow, 2013; Jonides, 1981). Studies which have assessed the link between cue-utilisation and working memory have shown that the inclusion of a memory array following cue presentation on some trials can enhance cue-maintenance even in highly unpredictive contexts (Carlisle & Woodman, 2011; Kiyonaga et al., 2012; Soto & Humphreys, 2007; Soto et al., 2008). Lastly, presentation of an irrelevant item during cue-maintenance can disrupt this process and reduce the signal for the maintained item (Clapp & Gazzaley, 2012) and hence affect cue-utilisation levels. Overall, these distinctions make it difficult to understand whether block predictiveness is the driving factor for modulating endogenous cue-utilisation. As such it is questionable what level of block predictiveness is required to encourage young children to maintain cues endogenously.

From this discussion of the past research, it has been shown that block predictiveness plays a key role in manipulating the form of attentional control mechanism used to guide attention. To further examine this in children, one must aim to assess block predictiveness in the absence of other methodological factors to ascertain the level required to promote endogenous control in young children.

The Current Study

The method used in Chapter 3 manipulated block predictiveness in three conditions (Mostly Predictive - 66.67% valid: 33.33% invalid, Low Predictive - 33.33% invalid: 66.67% invalid and Baseline - 100% neutral). It was expected, and found in nine- to 11-year-olds and adults, that cue-utilisation levels would be highest in the Mostly Predictive block as this context encouraged maintenance of a cue which usually guided attention towards the target. In comparison to past research, block predictiveness levels including 66.67% valid trials is considered low, as evidence has shown enhanced cue-utilisation for 80-100% valid blocks, relative to 50% valid and 100% neutral block conditions (Arita et al., 2012; Corbetta et al., 2000; Kiyonaga et al., 2012; Laarni, 2001; Noonan et al., 2016; Theeuwes & van der Burg, 2008). It is possible that the Mostly Predictive block in Chapter 3 did not encourage endogenous cue-utilisation in five- to six-year-olds, as they may have been deemed as irrelevant or not helpful enough to dissuade this age-group from utilising their “default” mechanism, exogenous control (Chevalier et al., 2015, 2020). It is noted that metacognitive awareness is still developing during ages five to six and so this age-group may be less effective at monitoring the cue to adjust their behavioural response towards it (Chevalier & Blaye, 2016; Chevalier, Blaye, Dufau & Lucenet, 2010; Niebaum, Chevalier, Guild & Munakata, 2019). Nevertheless, the aforementioned cueing research has indicated that children as young as five are able to adjust their cue-utilisation levels with respect to 80% valid vs 50% valid block predictiveness modulations. Therefore, this warrants further examination of this factor in the absence of other methodological manipulations.

The current chapter aimed to assess whether block predictiveness influenced cue-utilisation in children. Specifically, I asked children aged five to six and nine to 11 years (who were shown previously to have developed endogenous control) to complete three block conditions – two of which were replicated from Chapter 3 and one newly introduced condition. The block conditions were as follows: 1) Mostly Predictive block (66.67% valid, 33.33% invalid), 2) Baseline block (100% neutral) and 3) Always Predictive block (100% valid). The Always Predictive block is theorised to have the greatest incentive to maintain the highly predictive cues as it provides reliable information concerning the target and has been shown to yield the maximum levels of cue-utilisation, relative to other predictive block conditions (Kiyonaga et al., 2012; Noonan et al., 2016; Yantis & Jonides, 1990). To examine the influence of block predictiveness, I assessed this manipulation in the absence of the singleton distracter in the search-display; an item which has been shown to influence endogenous control by putting constraints on working memory storage (Fukuda & Vogel, 2011; Vogel, McCollough & Machizawa, 2005).

If children are able to utilise the cues endogenously to guide their attention, it is expected that they will experience a cue benefit (faster response times, better accuracy) on valid trials in both Predictive block conditions, compared to the Baseline block. More specifically, a greater cue benefit may be found for valid trials in the Always Predictive block (100% valid trials), relative to the Mostly Predictive block (66.67% valid trials). In addition it is expected that endogenous cue-utilisation will lead to a cue cost (slower response times, poorer accuracy) on invalid trials in the Mostly Predictive block, relative to the Baseline block. However, if children have *not* developed the ability to utilise cues endogenously, it is expected that there will be no differences in performance between trials in the Predictive blocks and the Baseline block.

It is predicted that nine- to 11-year-olds will utilise the cues endogenously, replicating the findings from Chapter 3 and previous research (Goldberg et al., 2001; Iarocci et al., 2009; Johnson et al., 2020; Shimi et al., 2014, 2015; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005). It is questionable however whether five- to six-year-olds, a *transition age-group*, have developed the ability to utilise cues endogenously as suggested by past research (Brodeur & Boden, 2000; Jakobsen et al., 2013; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2005) or if they rely on using an exogenous strategy as shown in Chapter 3 (Gaspelin et al., 2015; Johnson et al., 2020; Schul et al., 2003).

Method

The hypotheses and analyses for this study were pre-registered on the Open Science Framework (*see Appendix 5.1*).

Participants

38 five- to six-year-olds (M = 5.42 years, SD = .50 years, 17 female, 21 male) and 33 nine- to 11-year-olds (M = 10.00 years, SD = .83 years, 15 female, 18 male) participated in this study after exclusion. 16 participants were excluded from data analysis due to: attrition (5-6 years: N = 5), failure to understand instructions[13] (5-6 years: N = 2), not in prespecified age-range[14] (5-6 years: N = 2; 9-11 years: N = 3) and parental/carer report of a formal diagnosis of Autistic Spectrum Disorder and/or Attention Deficit and Hyperactivity Disorder (9-11 years: N = 4). Of the included sample, participants completed the study either at a public engagement event (Summer Scientist Week; 5-6 years: N = 13; 9-11 years: 32) or university invite (5-6 years: N = 25; 9-11 years: 1). For more details, see overleaf.

A power analysis was conducted using the method described by D'Amico et al. (2001) and Osborne (2006). This method required the use of mean, standard deviation and correlation data to simulate the effect size for the interaction of interest. I powered for a Cue Validity (2 levels: valid, neutral) x Age-Group (2 levels: 5-6 years, 9-11 years) interaction using data from Wainwright and Bryson (2005). This analysis found 54 participants in each age-group were required to attain a power of .8 at an alpha criterion of .01[15]. It should be noted that Wainwright and Bryson (2005) had relatively small sample sizes (5-6 years: N = 14; 9-11 years: N = 13) and they used location cues, which incorporated valid (80% of trials), invalid (3.33% of trials) and neutral trials (16.67% of trials) in one block condition with two stimulus onset asynchronies (100, 800ms) for cue presentation[16]. Nevertheless, from

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[13] Failure to understand instructions was assessed in the practice stages following the same criteria used in Chapter 3. If a participant failed any of the four practice stages based on the criteria highlighted in the Procedure, they were excluded from the data analysis.

[14] 4 years: N = 1; 7 years: N = 1; 8 years: N = 3.

[15] An alpha criterion of .01 was used for this power analysis to ensure a conservative approach was taken. All further analyses in the current Chapter and future Chapters used this alpha criterion and is highlighted in the Results.

[16] The effect size simulated from the power analysis is not known as I did not have access to the full dataset, nor were effect sizes for the interaction reported in Wainwright and Bryson (2005).

the reviewed cueing research, Wainwright and Bryson (2005) included the age-groups of interest and the relevant data required for this power analysis.

Data collection took place in two forms: 1) public engagement event and 2) university invite. The public engagement event, Summer Scientist Week, was hosted by the University of Nottingham Perception, Action, Human Development and Learning Team. In this one-week event, children aged 4-12 years, accompanied by parents or carers, were invited to take part in some fun research games. I also invited children and parents/carers to visit the university in the school holidays and on the weekends, where children could take part in the study in a lab setting. For data collection at the public engagement event, ethical approval was granted from the School of Psychology Ethics Committee for a joint ethics application with other researchers conducting research studies at Summer Scientist Week. For data collection at the university, ethical approval and a chair amendment was granted from the School of Psychology Ethics Committee to approve the advertising of the study on reliable social media platforms. Approval was gained from school operations to permit the conduct of data collection with adult-accompanied children in the School of Psychology on the weekends. In both forms of data collection, informed consent was gained by parents/carers and verbal assent was gained from child participants.

All data collection via university invite was conducted by emailing parents/carers on the Human Development and Learning participants database, as well as advertising on Facebook parent groups. Due to the quick success of this approach, I had sent parent letters to local schools in Nottingham in February 2020 to widen my participant pool, with hopes that data collection would be complete by the end of March 2020. However, due to COVID-19 data collection was discontinued. Data analysis was conducted on the existing dataset, with hopes that data collection will resume when it is safe to do so.

Design

A mixed design was used in this study. Participants from two age-groups (2 levels: 5-6, 9-11 years) were asked to complete three conditions which manipulated Block Predictiveness using different proportions of Cue Validity trials (3 levels: Mostly Predictive – 66.67% valid, 33.33% invalid trials; Baseline – 100% neutral trials; Always Predictive – 100% valid trials). This study aimed to assess 1) cue benefit (valid vs neutral trials) and 2) cue cost (invalid vs neutral trials). For the first aim, cue benefit will be examined by comparing performance on valid trials in the Mostly Predictive and Always Predictive blocks with neutral trials in the Baseline block. For the second aim, cue cost will be examined by comparing performance on invalid trials in the Mostly Predictive block with neutral trials in the Baseline block (the Always Predictive will be excluded from this aim as it does not include any invalid trials).

The method used in the current study differed from Chapter 3 in the following ways:

1) The inclusion of the Always Predictive block (100% valid trials) to assess block predictiveness effects on cue-utilisation.
2) The Low Predictive block (33.33% valid, 66.67% invalid trials) was excluded from this study. This was due to practical constraints as participants only had 15-20 minutes to complete the study. Also, as shown in Chapter 3, high levels of block predictability led to higher cueing ratios in nine- to 11-year-olds and adults, relative to Low Predictive and Baseline blocks. As the current study was concerned with encouraging cue-use, the Low Predictive block was not of interest for the research questions.
3) The exclusion of the singleton distracter from the search-display, to control for possible maintenance of this item in working memory (Fukuda & Vogel, 2011; Vogel et al., 2005).
4) Reduced number of trials in each block condition (Chapter 3: 144 trials per block condition; current Chapter: 48 trials per block condition). Due to the exclusion of the singleton distracter, counterbalancing of the stimuli was

less restricted. This enabled all block conditions to be completed in one session, rather than three sessions.

Stimuli, Apparatus & Materials

All stimuli were replicated from the method used in Chapter 3, with the exclusion of the singleton distracter (black diamond item). The same experimental equipment and software (PsychoPy version 1.85; Peirce, 2019) used in Chapter 3, was kept constant in the current study.

Procedure

Participants at Summer Scientist Week took part in the study in a large darkened room shared by two other researchers. Those recruited via university invite took part in a darkened noise-controlled lab which was not shared by others. In both settings noise was kept to a minimum to reduce distraction. Participants were invited to play three levels of the "Let's Find Dory" game. All practice phases (Response Practice – no cue; familiarisation with buttons; Cue Practice – familiarisation with cue task) and instructions concerning the aim of the game (i.e. follow Dory's trail/ tilted line target) and the cues (i.e. Dory's clues) were replicated from Chapter 3. Participants completed the Response Practice phase at the beginning of the study. For each block condition, participants completed a Cue Practice phase which replicated the proportion of trial types in each of the experimental conditions (66.67% valid, 100% neutral & 100% valid). As done previously, participants were asked whether they thought Dory's clues were helpful or not in informing them about the trail/tilted line. The additional criteria used in this study required participants to answer *"yes they are helpful"* in response to the Always Predictive Cue Practice phase. The same criteria used in Chapter 3 was used to allow participants to repeat a practice phase (if =/> 3 inaccurate responses; answer to Cue Practice question did not match criteria) and exclude a participant (if criteria above continued after 3 repeat attempts). As mentioned in *Participants*, two participants in the five to six years age-group met this latter criteria and were excluded from the analysis.

Participants completed a total of 144 experimental trials (48 trials per block condition). In between each block, participants were provided with a break in the form of a mini-game to reduce fatigue and to inform participants that they had completed a level of the game. This mini-game consisted of Dory the fish in the centre of the screen and four cartoon images (fishermen, seagull, jellyfish and seaweed) surrounding her. All items were sized 4.90° width x 4.90° height. Participants were asked to press the arrow keys as fast as they could in response to the location of the seaweed. Correct responses led Dory to increase 1.5 times in size to create the illusion that they were getting closer to Dory (incorrect responses decreased Dory's size). Participants completed 8 trials of the mini-game before they saw Dory "swimming" away across the screen, to encourage them to continue with the next level (block condition). This mini-game was presented twice in both break periods between block conditions. Images of Dory and other cartoon images were only presented in instruction screens and the mini-game screens. I aimed to counterbalance the order of the block conditions for each age-group but this was not achieved as data collection was interrupted[17]. Once data collection for this study has been completed, analyses to consider the presence of order effects will be conducted. At the end of the task, participants were provided with an inconvenience allowance in the form of a token which could be spent on fun-fair games (face painting, hook a duck etc.) at Summer Scientist Week, or they were provided with stickers, a certificate and a novelty pencil if recruited through university invite.

Results

Data Processing

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[17] In five- to six-year-olds, two (out of six) orders were completed one additional time. In nine- to 11-year-olds, three (out of six) orders were completed one additional time. Furthermore, sample sizes differed between age-groups (5-6 years: N = 38; 9-11 years: N = 33) and so some orders were assigned to more five- to six-year-olds than nine- to 11-year-olds.

For the analyses of both median response times and mean accuracy, the first trial of each block condition was filtered from the data (2.08% data removal). Outlier response times were removed if they were more than +/- 4 standard deviations away from a participant's median response time in each block condition (.63% data removal). Inaccurate trials were removed from the analysis of response times (5.74% data removal).

Outlying participants were assessed by calculating each participant's Mahalanobis distance from a chi-squared distribution in each age-group, based on median response time and mean accuracy data across Block and Cue Validity conditions. Due to the number of conditions included in this analysis (eight conditions), a conservative approach was used (cumulative probability $p < .001$) to classify a participant as a multivariate outlier. No multivariate outliers were found.

For the main analyses, a conservative alpha criterion was used, where p must be < .01 to be classed as significant. If p is more than or equal to .01, this will be defined as non-significant and in the latter case, results will not be overinterpreted (*see pre-registration in Appendix 5.1*). This differs from the previous Chapters 2 - 4 which used an alpha criterion where p must be < .05 to be significant. A conservative approach was used in this study and later studies so that I could reduce the likelihood of finding a false positive result. In the current analyses, if Mauchly's Test of Sphericity was violated ($p < .01$), Greenhouse Geisser correction was used to correct for inflation of the F-ratio and reduce the chances of making a type 1 error. If a significant main effect (which has 3 levels) and/or interaction was found, simple main effects analysis was conducted with Bonferroni correction applied to reduce type 1 error.

Analysis

This study aimed to understand the influence of block predictiveness on cue-utilisation in early- (5-6 years) and mid-childhood (9-11 years). I investigated whether the predictive context influences the use of endogenous control in a Cued Visual Search task. By manipulating the proportion of valid, invalid and neutral cues in each block condition (3 levels: Always Predictive – 100% valid cues; Mostly Predictive – 66.67% valid cues, 33.33% invalid cues; Baseline – 100% neutral cues), three aims were assessed:

1. To understand whether children experience a cue benefit on valid trials in differentially predictive contexts, relative to neutral cues in the Baseline block.
2. To assess whether children experience a cue cost on invalid trials in a Mostly Predictive context, relative to neutral cues in the Baseline block.
3. An exploratory aim, which was not included in the pre-registration, considered children's cueing ratios, to understand if they were able to sustain cue-use across the block of trials in the Mostly Predictive condition.
4. An additional exploratory aim, which was not included in the pre-registration, compared cue-use in the current study to cue-use in the study from Chapter 3. This aim assessed whether mere exposure to a singleton distracter in the task used in Chapter 3 made cue-use more difficult for children, relative to the current study which did not include a singleton distracter.

If participants have developed endogenous control, it was expected that they would benefit (faster response times, better accuracy) from valid cues in guiding their attention towards the target, particularly in the Always Predictive block relative to all other block conditions. They would also experience a cost to performance (slower response times, poorer accuracy) on invalid trials in the Mostly Predictive block, compared to the Baseline block. In addition, for the first exploratory aim, it was expected that children who were able to sustain cue-use would have significantly larger cueing ratios in the Mostly Predictive block compared to the Baseline block. For the second exploratory aim, if cue-use is hindered by exposure to a singleton distracter, cue-use would be greater in the current chapter relative to Chapter 3, particularly in five- to six-year-olds who have been shown to experience difficulties with updating and disregarding irrelevant information from their working memory store (Cowan, 2010, 2011).

Cue Benefit from Valid Cues

For the first aim, separate Block (3 levels: Always Predictive, Mostly Predictive, Baseline) x Age-Group (2 levels: 5-6, 9-11 years) mixed ANOVAs were conducted on median response times and mean accuracy. This analysis included data from valid trials in the Predictive block conditions and neutral trials from the Baseline block only. Data from invalid trials in the Mostly Predictive block were excluded from this analysis.

Response Time

The Block x Age Group interaction was non-significant ($F(2, 138) = .27$, $p = .763$, $\eta_p^2 = .004$; *see Figure 5.1 overleaf*). A significant main effect of Block was found ($F(2, 138) = 15.59$, $p < .001$, $\eta_p^2 = .18$; *see Figure 5.2 overleaf*). This showed that response times on valid trials in the Always Predictive block were faster than neutral trials in the Baseline block ($p < .001$; Cohen's $d = .62$ [99% CI .29, .95], Hedges' $g = .62$ [99% CI .28, .95]), but not faster than valid trials in the Mostly Predictive block as this difference did not reach significance ($p = .017$; Cohen's $d = .34$ [99% CI .03, .66], Hedges' $g = .34$ [99% CI .03, .65]). Response times on valid trials in the Mostly Predictive block did not significantly differ from neutral trials in the Baseline block ($p = .01$; Cohen's $d = .37$ [99% CI .05, .68], Hedges' $g = .37$ [99% CI .05, .68]). A significant main effect of Age-Group was also found ($F(1, 69) = 107.83$, $p < .001$, $\eta_p^2 = .61$). This showed that five- to six-year-olds were significantly slower (M = 1.93, SE = .07 [99% CI 1.76, 2.10]) than nine- to 11-year-olds (M = .94, SE = .07 [99% CI .76, 1.13]).

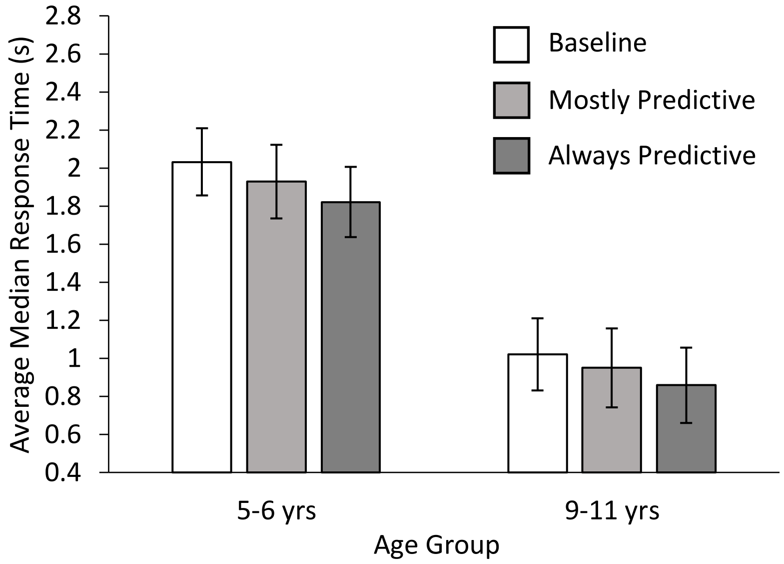

Figure 5.1. Average median response times (s) for 5-6 year-olds and 9-11 year-olds on neutral trials in the Baseline block (white), valid trials in the Mostly Predictive (light grey) and Always Predictive (dark grey) blocks. Error bars represent 99% confidence intervals.

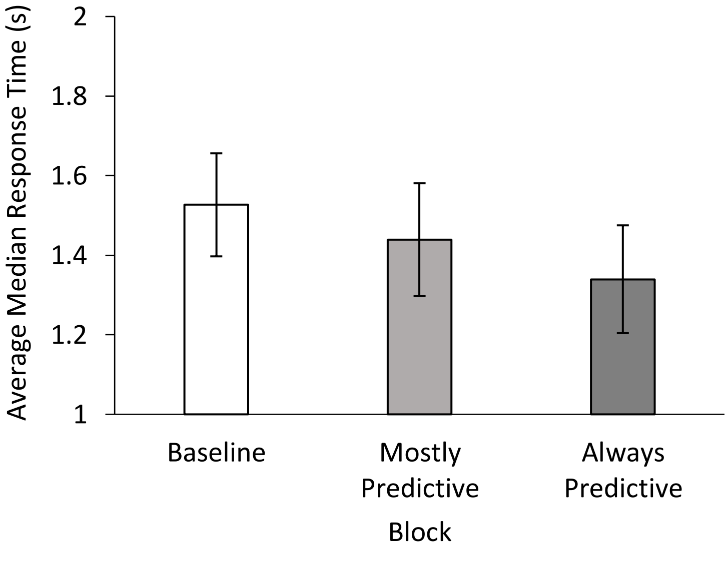

Figure 5.2. Average median response times (s) on neutral trials in the Baseline block (white), valid trials in the Mostly Predictive (light grey) and Always Predictive (dark grey) blocks. Error bars represent 99% confidence intervals.

Accuracy

The Block x Age Group interaction was non-significant (*F*(1.56, 107.46) = .47 , *p* = .58, η_p^2 = .01; *see Table 5.1*). Both main effects of Block (*F*(1.56, 107.46) = .59, *p* = .517, η_p^2 = .01; Always Predictive: M = .95, SE = .01 [99% .94, .97]; Mostly Predictive: M = .94, SE = .01 [99%CI .92, .97]; Baseline: M = .95, SE = .01 [99% CI .93, .96]) and Age-Group (*F*(1, 69) = 3.40, *p* = .069, η_p^2 = .05; 5-6 years: M = .94, SE = .01 [99% CI .92, .96]; 9-11 years: M = .96, SE = .01 [99% CI .94, .98]) were also non-significant.

Table 5.1. Mean accuracy, Standard Error and 99% Confidence Intervals for all Block conditions and Age-Groups.

	5- to 6-year-olds			*9- to 11-year-olds*		
	M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Baseline	.94	.01	.92, .97	.95	.01	.93, .98
Mostly Predictive	.93	.01	.89, .96	.96	.01	.92, .99
Always Predictive	.94	.01	.92, .96	.96	.01	.94, .98

Note: M = Mean; SE = Standard Error; 99% CI = 99% Confidence Intervals [lower, upper bound].

Cue Cost from Invalid Cues

For the second aim, separate Cue Validity (3 levels: valid, invalid, neutral) x Age-Group mixed ANOVAs were conducted on median responses times and mean accuracy. Here, I included data from valid and invalid trials in the Mostly Predictive block as well as neutral trials from the Baseline block. The Always Predictive block condition was excluded from this analysis.

Response Time

The Cue Validity x Age-Group interaction was non-significant (*F*(1.36, 93.93) = 2.25, *p* = .129, η_p^2 = .03; *see Figure 5.3*). A main effect of Age-Group was found (*F*(1, 69) = 97.85, *p* < .001, η_p^2 = .59). This showed that five- to six-year-olds were significantly slower (M = 2.12, SE = .07 [99% CI 1.92, 2.31]) than nine- to 11-year-olds (M = 1.06, SE = .08 [99% CI .86, 1.27]). A main effect of Cue Validity was also found (*F*(1.36, 93.93) = 30.13, *p* < .001, η_p^2 = .30; *see*

Figure 5.4 overleaf). Planned t-tests with Bonferroni correction were conducted to assess this main effect. This avoids repeat comparisons between valid (Mostly Predictive block) and neutral trials (Baseline block) that were assessed in the previous analysis for Cue Benefit. Response times were significantly slower on invalid trials in the Mostly Predictive block relative to valid trials in the same block condition ($t(70) = 7.01$, $p < .001$, two-tailed, [99% CI_{Mdiff} .23, .51], Cohen's $d = .83$[18] [99% CI .48, 1.19], Hedges' $g = .83$[19] [99% CI .47, 1.18]). Response times on invalid trials in the Mostly Predictive block were also slower than neutral trials in the Baseline block ($t(70) = 4.66$, $p < .001$, two-tailed, [99% CI_{Mdiff} .12, .44] Cohen's $d = .55$ [99% CI .22, .88], Hedges' $g = .55$ [99% CI .22, .88]). The previous analysis (Cue Benefit) showed that response times on valid trials in the Mostly Predictive block did not significantly differ from neutral trials in the Baseline block ($p = .01$; Cohen's $d = .37$ [99% CI .05, .68], Hedges' $g = .37$ [99% CI .05, .68]). This comparison was not repeated in the current analysis of Cue Costs.

Accuracy

The Cue Validity x Age-Group interaction was non-significant ($F(2, 138) = 1.36$, $p = .26$, $\eta_p^2 = .02$; *see Table 5.2*). A main effect of Age-Group was not significant ($F(1, 69) = 3.82$, $p = .055$, $\eta_p^2 = .05$; 5-6 years: M = .92, SE = .01 [99% CI .89, .95]; 9-11 years: M = .95, SE = .01 [99% CI .92, .98]). The main effect of Cue Validity did not meet significance ($F(2, 138) = 4.77$, $p = .01$, $\eta_p^2 = .07$; invalid trials: M = .91, SE = .01 [99% CI .88, .95]; neutral trials: M = .94, SE = .01 [99% CI .92, .97]; valid trials: M = .94, SE = .01 [99%CI .92, .97]).

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[18] Cohen's $d_z = \frac{M_{diff}}{\sqrt{\frac{\Sigma\left(X_{diff} - M_{diff}\right)^2}{N-1}}}$ was used to calculate the mean difference between two correlated within-subject measures, which is divided by the standard deviation of the difference scores. I also checked the calculation using data from the paired sample t-test (t value and number of participants) in the formula: $d_z = \frac{t}{\sqrt{N}}$ which confirmed the original calculation (Lakens, 2013; Rosenthal, Cooper & Hedges, 1994).

[19] Cohen's d_z is based on sample data which provides a biased estimate of a population effect size (Hedges & Olkin, 1985). To correct for this, Hedges g used the same calculation of Cohen's d_z with a correction factor applied: Hedges $g = d_z \times \left(1 - \frac{3}{4(n_1+n_2)-9}\right)$.

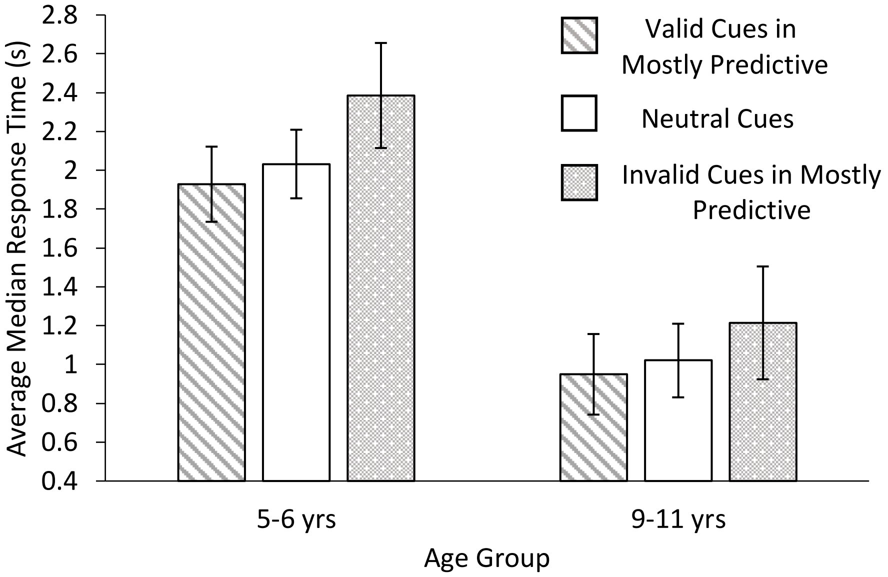


Figure 5.3. Average median response times (s) for two age-groups on trials with Neutral cues in the Baseline block (white), Valid cues in the Mostly Predictive block (stripes) and Invalid Cues in the Mostly Predictive block (dots). Error bars represent 99% confidence intervals.

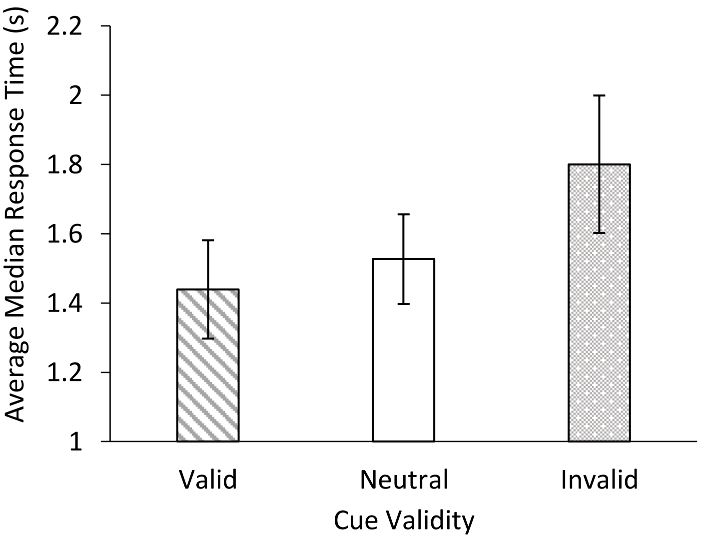


Figure 5.4. Average median response times (s) on trials with Neutral cues in the Baseline block (white), Valid cues in the Mostly Predictive block (stripes) and Invalid Cues in the Mostly Predictive block (dots). Error bars represent 99% confidence intervals.

Table 5.2. Mean accuracy, Standard Error and 99% Confidence Intervals for all Age-Groups and Cue Validity levels- in each block condition.

	5- to 6-year-olds			*9- to 11-year-olds*		
	M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Neutral- Baseline	.94	.01	.92, .97	.95	.01	.93, .98
Valid- Mostly Predictive	.93	.01	.89, .96	.96	.01	.92, .99
Invalid- Mostly Predictive	.89	.02	.84, .94	.94	.02	.89, .99

Note: M = Mean; SE = Standard Error; 99% CI = 99% confidence intervals [lower, upper bound].

Exploratory Analyses

Cueing Ratios

The analyses highlighted above questioned cue-utilisation at the trial level within each block condition. The analysis of Cue Cost showed a significant difference between invalid and valid response times in the Mostly Predictive block. To further consider this difference, the current exploratory analysis will consider cue-utilisation at the block level using cueing ratios which also controls for age-related differences in response times. Neutral trials in the Baseline block were assigned “valid” and “invalid” variables using the same procedure used in Chapter 3. This matched assigned trials to the Mostly Predictive block, to keep search-displays (but not cue-displays) constant between block conditions. Cueing ratios were calculated (Median Response Time: invalid / valid; Mean Accuracy: valid / invalid) for the Mostly Predictive block and the Baseline block. Cueing ratios above 1, suggest high levels of cue-utilisation. Separate 2 (Block: Mostly Predictive, Baseline) x 2 (Age-Group) mixed ANOVAs were conducted on average cueing ratios for response times and accuracy.

Response Time

The Block x Age-Group interaction was non-significant ($F(1, 69) = .69$, $p = .409$, $\eta_p^2 = .01$; *see Figure 5.5*). The main effect of Age-Group was also non-significant ($F(1, 69) = .04$, $p = .841$, $\eta_p^2 = .001$; 5-6 years: M = 1.14, SE = .03 [99% CI 1.07, 1.21]; 9-11 years: M = 1.15, SE = .03 [99% CI 1.07, 1.22]). However, the main effect of Block met significance ($F(1, 69) = 62.49$, $p < .001$, $\eta_p^2 = .48$). This showed that participants had larger cueing ratios in the Mostly Predictive block compared to the Baseline block.

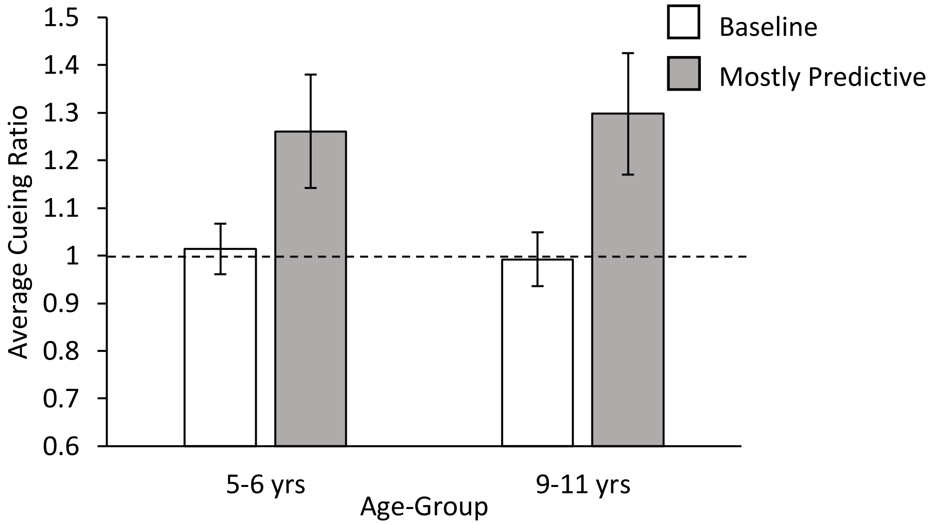


Figure 5.5. Average cueing ratios for the Baseline block (white bars) and the Mostly Predictive block (grey bars) in two age-groups. Error bars represent 99% confidence intervals.

Accuracy

The Block x Age-Group interaction ($F(1, 69) < .001$, $p = .992$, $\eta_p^2 < .001$; *see Table 5.3 overleaf*) was non-significant. Both main effects of Age-Group ($F(1, 69) = 2.42$, $p = .124$, $\eta_p^2 = .03$; 5-6 years: M = .97, SE = .01 [99% CI .94, 1.00]; 9-11 years: M = 1.00, SE = .01 [99% CI .96, 1.03]) and Block ($F(1, 69) = 2.38$, $p = .128$, $\eta_p^2 = .03$; Mostly Predictive: M = .97, SE = .01 [99% CI .93, 1.01]; Baseline: M = 1.00, SE = .01 [99% CI .97, 1.02]) were also not significant.

Table 5.3. Average cueing ratio for accuracy data, Standard Error and 99% confidence intervals for both Age-Groups in each block condition.

	5- to 6-year-olds			*9- to 11-year-olds*		
	M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Baseline	.98	.02	.94, 1.02	1.01	.02	.97, 1.05
Mostly Predictive	.96	.02	.91, 1.01	.98	.02	.93, 1.04

Note: M = Mean; SE = Standard Error; 99% CI = 99% confidence intervals [lower, upper bound].

Comparisons to Chapter 3

The last exploratory aim considered how cue-use in the current chapter compares to Chapter 3, where participants were exposed to a singleton distracter. It has been argued that the cognitive load of a task can be increased in those who find it difficult to disregard irrelevant information from their working memory store (Cowan, 2010, 2011; Fukuda & Vogel, 2011). It is possible that in Chapter 3, five- to six-year-olds found it difficult to utilise the cue in the Mostly Predictive block as they struggled to disregard the singleton distracter but in the current chapter, where there was no singleton distracter, they were able to utilise the cue to guide their attention. However, the current study had a reduced number trials per block (Chapter 5: N = 48 trials per block; Chapter 3: N = 144 trials per block) and so it is possible that cue-use was shown in the current chapter because five- to six-year-olds were able to sustain this skill over a shorter length of time (Ambrosi et al., 2016).

To consider this aim, cue-use was compared between Chapter 3 and the current chapter for five- to six- and 9- to 11-year-olds. For the results from Chapter 3, the first 48 trials of the Mostly Predictive and Baseline blocks were selected. This would allow me to directly compare cue-use between both studies whilst task length was controlled for.

Cue-use was assessed by conducting separate Cue Validity (3 levels: valid, invalid, neutral) x Chapter (2 levels: Chapter 3, Chapter 5) x Age-Group (2 levels: 5-6, 9-11 years) mixed ANOVAs on *singleton-absent trials* for median response time and mean accuracy data. This differs from my analyses in

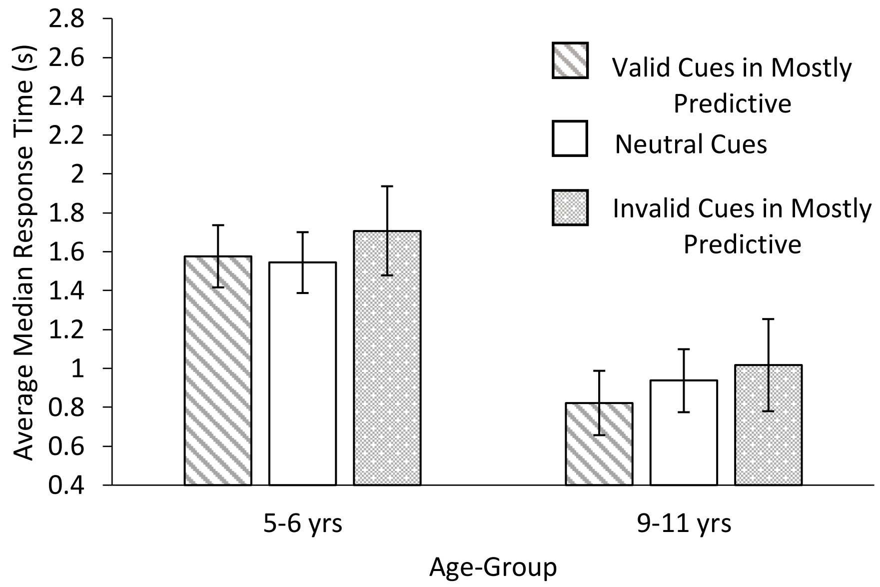
Chapter 3 where I used cueing ratios to assess cue-utilisation at the block level. This method of analysis was chosen as it would allow me to compare cue benefits (valid vs neutral) and cue costs (invalid vs neutral) in both study chapters at the trial level. This would allow me to gain more insight into the influence of different cues on attentional guidance (rather than focusing on whether they can sustain cue-use), in a task where participants are exposed to a distracting item (Chapter 3) and a task where they are not (current chapter). If exposure to a singleton distracter influenced cue-use, I would expect age-differences in cue benefits and costs between five- to six- and nine- to 11-year-olds in Chapter 3 but no such difference in the current chapter study.

Response Time

The Cue Validity x Chapter x Age-Group interaction was not significant ($F(1.63, 251.14) = 1.92$, $p = .157$, $\eta_p^2 = .01$; *see Figure 5.6 overleaf*). The Cue Validity x Chapter interaction approached but did not meet significance ($F(1.63, 251.14) = 4.79$, $p = .014$, $\eta_p^2 = .03$). The Cue Validity x Age-Group interaction was not significant ($F(1.63, 251.14) = 1.64$, $p = .200$, $\eta_p^2 = .01$). The Chapter x Age-Group interaction was significant ($F(1, 154) = 7.92$, $p = .006$, $\eta_p^2 = .05$). This showed that five- to six-year-olds who completed the study in Chapter 3 were slower than those in the same age-group in the current chapter ($p < .001$). No difference was found between chapters for nine- to 11-year-olds ($p = .155$). Within both chapter studies, five- to six-year-olds were slower than nine- to 11-year-olds (both *p*s < .001).

The main effect of Cue Validity ($F(1.63, 251.14) = 33.27$, $p < .001$, $\eta_p^2 = .18$) was significant and showed participants were slower on invalid trials (M = 1.58, SE = .05 [99% CI 1.46, 1.71]) compared to valid (M = 1.32, SE = .03 [99% CI 1.23, 1.41]) and neutral trials (M = 1.38, SE = .03 [99% CI 1.30, 1.47]; both *p*s < .001) but no difference was found between valid and neutral trials ($p = .052$). The Chapter main effect was significant ($F(1, 154) = 23.93$, $p < .001$, $\eta_p^2 = .13$) which showed participants in the current chapter study (M = 1.59, SE =

Chapter 3
(singleton-absent trials; exposed to singleton distracter)



Current chapter
(no singleton distracter)

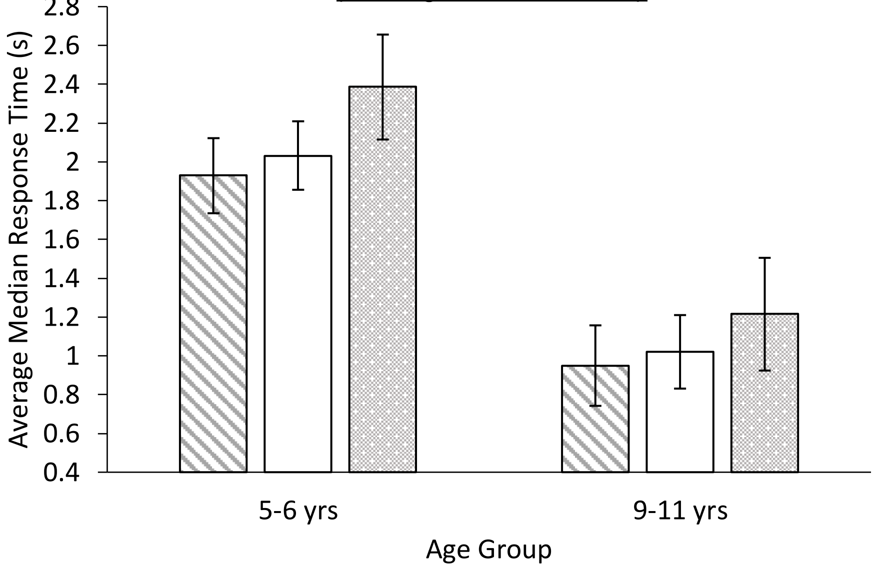


Figure 5.6. Average median response times (s) for two age-groups who completed the study in Chapter 3 (singleton-absent trials; top) and the study in the current chapter (bottom; graph also presented on page 131). Trials are presented as Neutral cues in the Baseline block (white), Valid cues in the Mostly Predictive block (stripes) and Invalid Cues in the Mostly Predictive block (dots). Error bars represent 99% confidence intervals. Note: the bottom graph from the current chapter is repeated here to ease comparison to Chapter 3 findings.

.05 [99% CI 1.46, 1.72]) were slower than participants in Chapter 3 (M = 1.27, SE = .04 [99% CI 1.15, 1.38]). Lastly, the Age-Group main effect was significant (*F*(1, 154) = 175.65, $p < .001$, $\eta_p^2 = .53$) as five- to six-year-olds (M = 1.86, SE = .05 [99% CI 1.75, 1.98]) were slower than nine- to 11-year-olds (M = .99, SE = .05 [99% CI .87, 1.12]).

Accuracy

The Cue Validity x Chapter x Age-Group interaction was significant (*F*(1.51, 232.43) = 6.37, $p = .005$, $\eta_p^2 = .04$; *see Table 5.4 overleaf*). In the Chapter 3 study, nine- to 11-year-olds had poorer accuracy on invalid trials relative to valid ($p < .001$) and neutral trials ($p = .001$); no difference was found between valid and neutral trials in this age-group ($p = 1.00$). Five- to six-year-olds in Chapter 3 and both age-groups in the current chapter showed no differences between all Cue Validity levels (all *p*s > .07). Comparisons between chapters showed that both age-groups in Chapter 3 and the current chapter did not differ in accuracy for each Cue Validity level (all *p*s > .04). Comparisons between age-groups showed that within each chapter, all age-groups did not differ from one another in all Cue Validity levels (all *p*s > .01). It should be noted however that one comparison approached but did not meet significance which would have indicated that in Chapter 3, nine- to 11-year-olds had poorer accuracy on invalid trials only, compared to five- to six-year-olds ($p = .019$).

The Cue Validity x Age-Group (*F*(1.51, 232.43) = 1.48, $p = .231$, $\eta_p^2 = .01$), the Cue Validity x Chapter (*F*(1.51, 232.43) = .32, $p = .665$, $\eta_p^2 = .002$) and the Chapter x Age-Group (*F*(1, 154) = 4.16, $p = .043$, $\eta_p^2 = .03$) interactions were non-significant. The main effect of Cue Validity (*F*(1.51, 232.43) = 10.13, $p < .001$, $\eta_p^2 = .06$) was significant and showed participants had less accuracy on invalid trials (M = .92, SE = .01 [99% CI .89, .94]) compared to valid (M = .95, SE = .01 [99% CI .93, .97]; $p = .001$) and neutral trials (M = .95, SE = .004 [99% CI .94, .96]; $p = .004$). No difference was found between valid and neutral trials ($p = 1.00$). The main effects of Chapter (*F*(1, 154) = .81, $p = .370$,

$\eta_p^2 = .01$) and Age-Group ($F(1, 154) = .53$, $p = .469$, $\eta_p^2 = .003$) were both non-significant.

Table 5.4. Mean accuracy, standard error and 99% confidence intervals for valid, invalid (in Mostly Predictive block) and neutral (in Baseline block) trials for two age-groups from Chapter 3 and the current chapter.

		5- to 6-year-olds			*9- to 11-year-olds*		
		M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Chapter 3	*Valid*	.95	.01	.92, .98	.96	.01	.93, .99
	Neutral	.95	.01	.93, .97	.97	.01	.95, .99
	Invalid	.95	.02	.90, 1.01	.88	.02	.82, .94
Current chapter	*Valid*	.93	.01	.89, .96	.96	.01	.92, .99
	Neutral	.94	.01	.92, .96	.95	.01	.93, .98
	Invalid	.89	.02	.83, .95	.94	.03	.87, 1.00

Note: M – mean; SE – standard error; 99% CI – 99% confidence intervals [lower, upper bound].

Discussion

The aim of the current study was to assess the influence of block predictiveness on cue-utilisation in early- (5-6 years) and mid-childhood (9-11 years). This was to further assess the finding from Chapter 3 which showed that five- to six-year-olds were unable to endogenously utilise cues, as no difference in cueing ability was found between the Mostly Predictive block and the Baseline block. Here, I investigated whether a context which is always predictive of the target's featural location would encourage endogenous cue-use, relative to mostly predictive and unpredictive (Baseline block) contexts in children. If children have developed the ability to endogenously maintain a cue to orient their attention, performance would benefit from valid cues in the Predictive blocks relative to Baseline, particularly the Always Predictive block. They were also expected to experience a cost on performance on invalid trials misallocating their attention in the Mostly Predictive block, relative to Baseline. The findings show that there were no age-differences in cue-utilisation between early- and mid-childhood. Both five- to six-year-olds and nine- to 11-year-olds were effective in maintaining early cue information to produce a benefit (only on valid trials in the Always Predictive block) as well as a cost (on invalid trials in the Mostly Predictive block) on their performance. Interestingly, children significantly benefited from valid trials when it was presented in a context which was Always Predictive compared to an unpredictive (Baseline) context. In addition, exploratory findings showed that they were able to sustain endogenous cue-use in the Mostly Predictive block, compared to the Baseline block. Comparisons between the current chapter (no singleton distracter) and Chapter 3 (singleton distracter exposure), suggested that cue-use for both age-groups did not significantly differ between chapters (with the exception of accuracy data). I will discuss the findings before considering possible reasonings for the results and the contrast in evidence from Chapter 3.

Research has argued that higher levels of block predictiveness increases the incentive to maintain early cue information to guide attention for an upcoming target (Arita et al., 2012; Yantis & Jonides, 1990; Weaver et al., 2014). The Always Predictive block created maximum incentive to maintain the cues endogenously, as the cue always provided reliable information concerning the feature of the target. The current study showed that, in some cases, five- to six-year-olds and nine- to 11-year-olds have developed the ability to endogenously orient their attention[20]. On valid trials, children were significantly faster to respond to the target in the Always Predictive block, relative to neutral trials in the Baseline block. This suggests that children intentionally maintained the cues in the Always Predictive block to anticipate the feature of the target, rather than merely attended to them as they did in the Baseline block. Thereby suggesting that children's attentional allocation benefited from a context where they were always provided with reliable information from the cue.

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[20] No significant difference was found between valid trials in the Mostly Predictive block and neutral trials in the Baseline block. For more discussion on this, see Limitations.

This study further assessed the findings from Chapter 3, to examine whether cue-utilisation is shown in a mostly predictive context. The cues in the Mostly Predictive block provided valid information concerning the target, most of the time (66.67%). Arguably, this level of block predictiveness may have been too low to encourage children to maintain the cue (Jonides, 1981; Leclercq & Siéroff, 2013). In the current study, the findings showed no age-differences in performance during the Mostly Predictive block. Specifically, both age-groups experienced a cue cost as they were slower on invalid trials in this condition, compared to valid trials in the same block and neutral trials in the Baseline block. It should be noted however that no significant difference was found between valid trials in the Mostly Predictive block and neutral trials in the Baseline block. In this comparison, *p* approached but did not meet significance (*p* = .01). That being said, Cohen's *d* showed this difference had a small-to-medium effect size (*d* = .37) which is indicative of a moderate benefit from valid trials in the Mostly Predictive block, relative to neutral trials in the Baseline block. This further highlights that this finding should be taken with caution and firm conclusions on this particular result cannot be made until data collection has been completed (*for further discussion, see Limitations*).

The assessment of cue-use at the block level showed that cueing ratios were significantly higher in the Mostly Predictive block relative to the Baseline block for both age-groups; no age-difference was found. Altogether, these findings may indicate that five- to six-year-olds were as adept as nine- to 11-year-olds at utilising the cue in a context where the cue was predictive of the target 66.67% of the time and were able to sustain this across trials in the block. This suggests that children as young as five have enough incentive from a mostly predictive context to encourage them to endogenously maintain early cue information to guide their attention (as demonstrated from invalid trials). This opposes previous evidence which have suggested that 80% predictive contexts are required to encourage endogenous control (Iarroci et al., 2009; Leclercq & Siéroff, 2013; Theeuwes & van der Burg, 2008;

Wainwright & Bryson, 2002, 2005). This finding also contrasts with Chapter 3 which showed non-significant differences in cueing ratios for five- to six-year-olds, but not nine- to 11-year-olds, between the Mostly Predictive block and the Baseline block. This finding should be taken with caution however as, as mentioned previously, no difference was found between valid trials in the Mostly Predictive block and the neutral trials in the Baseline block but a small-to-medium effect size was shown (*see Limitations*).

The current study has extended the findings from past research by exploring the influence of block predictiveness on cue-utilisation without the presence of other manipulated factors. The findings support past research which found endogenous orienting in five- to six-year-olds and nine- to 11-year-olds when block predictiveness was set to 80% valid (to 20% invalid; Brodeur & Enns, 1997; Brodeur & Boden, 2000; Iarocci et al., 2009; Jakobsen et al., 2013; Leclercq & Siéroff, 2013; Wainwright & Bryson, 2002, 2005). All of these studies manipulated other factors which influence cue-utilisation, such as stimulus onset asynchrony (SOAs) where SOAs below 200ms are known to encourage exogenous orienting (Corbetta et al., 2000; Berger et al., 2005; Jonides, 1981). As the SOA manipulation was intermixed in trials within the 80% block conditions in the aforementioned research, it is difficult to disentangle exogenous vs endogenous orienting responses, as cueing effects were averaged across SOA trials in the analyses. It is possible that the large cueing effects found in five- to six-year-olds in past research is not the product of an inhibition deficit on invalid trials (Brodeur & Boden, 2000) but may be a result of exogenous + endogenous orienting from the SOA manipulation.

Thus, the current study has extended the findings by showing both age-groups 1) benefited from an always predictive cue, 2) experienced a cost from invalid cues in a mostly predictive (66.67% valid) context and 3) cue-utilisation was sustained and higher in the Mostly Predictive block compared to the Baseline block. Above all, no age-differences were found in cue-use between five- to six-year-olds and nine- to 11-year-olds for all three of the findings above. This could suggest that an abled form of endogenous cue-utilisation which facilitates children in guiding attention, has already developed by ages five to six. This supports more recent findings that showed response time (Hermens, 2018) and saccadic (Landry et al., 2019) cueing effects did not differ between six- to 11-year-olds, as well as evidence which showed the spatial deployment of attention becomes stable by age six (Dye & Bavelier, 2010; Johnson et al., 2016). Therefore, by exclusively examining the role of block predictiveness, this study was able to show that both five- to six-year-olds and nine- to 11-year-olds were as effective as one another in using endogenous control in the Cued Visual Search task. I will now consider the possible line of reasonings for the results in the current study as well as question why the findings for five- to six-year-olds differ from Chapter 3.

Always Predictive Block

Research has argued that metacognition plays an important role in block predictiveness effects (Chevalier et al., 2020). It is possible that for block predictiveness to effectively encourage maintenance of the cue in a mostly predictive context, monitoring of the task or good metacognitive ability may be required. Metacognition is often referred to as the ability to be aware of one's internal thoughts, abilities or an external task (Smith, Shields & Washburn, 2003). For instance, good metacognitive ability enables us to *monitor* a task (i.e. the cues are usually helping me find the target) and this can be fed back to adjust our *control* on our behaviour (i.e. maintain the cues to guide attention; Nelson, 1990). By this definition, higher block predictiveness may yield higher levels of cue-utilisation, as task monitoring of the cue enables participants to adjust their behaviour accordingly. The presence of an invalid cue within a block condition could produce *demand signals* to be less reliant on or modulate the response towards cued information. On this basis, metacognitive task monitoring would predict faster response times on valid trials in a context where the cue is always predictive relative to mostly predictive. However, this difference did not reach significance in the current study (*p* = .017). This suggests that valid cues in both the Always Predictive and the Mostly Predictive blocks facilitated search for the target irrespective of overall block predictiveness levels (*see Limitations for Mostly Predictive - valid vs neutral discussion*). Furthermore, metacognitive task monitoring has been shown to be in development during ages five to six, but improves by ages nine to 11 (Chevalier et al., 2010, 2020; Niebaum et al., 2020). Despite this, no age-related differences were found in cue-utilisation performance in the current study. Overall, the findings could suggest that metacognitive monitoring may play a small role in influencing cue-utilisation in the current study (*see Overall Predictiveness next for an alternative account of metacognitive monitoring*). It should be noted however, that a small-to-medium effect size was found for this difference (Cohen's *d* = .34) which indicates a moderate improvement between valid trials in the Mostly Predictive block and valid trials in the Always Predictive block. Thus, firm conclusions cannot be made about this finding until data collection for this study has been completed.

Comparisons to Chapter 3

Of crucial relevance is to understand the reasoning for the differential results for five- to six-year-olds in this study compared to Chapter 3. In Chapter 3, the findings for five- to six-year-olds showed that 1) cueing ratios in the Mostly Predictive block did not significantly differ from the Baseline block and 2) individuals aged five to six who were better at maintaining the cue in the Mostly Predictive block, experienced more distraction in the Baseline block; suggestive of a trade-off between maintenance and inhibition skills at this age. It is important to note that a more conservative analytical approach (alpha = .01) was used in the current chapter relative to Chapter 3 (alpha = .05). Nevertheless, in Chapter 3, cue-use in the Mostly Predictive block was significantly smaller in five- to six-year-olds compared to nine- to 11-year-olds at the *p* < .01 level (*p* = .002). In contrast to this, no age difference was found in cue-use in the current chapter despite using the same Mostly Predictive block (except less trials and without a singleton distracter). I will first discuss the role of working memory in relation to the singleton distracter and differences in block length, before considering the results from the exploratory analysis which compared cue-use between Chapter 3 and the current chapter.

It is argued that the presence of a singleton distracter can increase the cognitive load of the task in individuals who have less control over their working memory ability (Cowan, 2010; Fukuda & Vogel, 2009, 2011). Cognitive Load theory (Lavie, 1995; Lavie et al., 2004) suggests working memory plays an active role in maintaining attentional priorities for items, enabling the biasing of attention towards a high-priority target and away from low-priority distracter items. Importantly, this theory suggests that situations where cognitive load is high means that working memory capacities are being drained, reducing the availability of these resources for selectively attending to task-relevant stimuli. Evidence has shown that adults with low working memory capacities were poorer at inhibiting a singleton distracter compared to high-capacity adults (Fukuda & Vogel, 2009, 2011). In addition, when participants were informed to search for two targets but ignore the two distracter items, it was only the high-capacity individuals who were able to successfully inhibit the distracters as shown by their reduced Contralateral Delay Activity (CDA; signal of encoding and maintenance in visual working memory; Vogel & Machizawa, 2004; Vogel et al., 2005). It was reasoned that those who have less control over their working memory storage may be prone to maintaining both task-relevant and task-irrelevant items in this store which in turn could increase the cognitive load of the task.

It is reasonable to suggest that the cognitive load of the task was reduced in the current study relative to Chapter 3, due to the absence of the singleton distracter. The inclusion of this item in Chapter 3 may have led to the storage of this item in working memory in those who have less control over the updating of information in this store. Children are considered to have less control over their working memory storage (for a review, see Cowan, 2010, 2011). Specifically between ages five and six when working memory ability has been shown to make marked improvements and is related to structural changes in grey matter reduction (Carlson, 2005; Cowan et al., 2005; Diamond, 2013; Kharitonova, Martin, Gabrieli & Sheridan, 2013; Kharitonova, Winter & Sheridan, 2015). In correspondence with this, children aged five to six who have developed endogenous (proactive) control have been shown to experience greater distraction when the cognitive load of the task was increased, by introducing a secondary motor task during image maintenance in the delayed match-to-sample task (Blackwell & Munakata, 2014; Blackwell et al., 2014). It is possible that in Chapter 3 the presence of the singleton distracter led to this item being maintained in working memory storage. This may have inadvertently increased the cognitive load of the task for children aged five to six, who may have less control over updating and disregarding this irrelevant information; leading to reduced cue-maintenance. In contrast, in the current study, cue-maintenance may not have been influenced by increased cognitive load due to the absence of the singleton distracter. Therefore, there is a basis to question whether the singleton distracter influenced cue-utilisation in five- to six-year-olds.

Alternatively, endogenous cue-utilisation sustained at the block level may be influenced by the length of block conditions. The current study showed prolonged use of endogenous cues in children as exemplified by higher cueing ratios in the Mostly Predictive block compared to the Baseline block, which was not found for five- to six-year-olds in Chapter 3. It is important to note however, that children were required to use endogenous control over a shorter block of trials (N = 48 trials per block) compared to Chapter 3 (N = 144 trials per block). Past research has also shown that five- to six-year-olds can use endogenous (proactive) control on a trial-by-trial basis but not at the block level in the Stroop, Simon and Flanker tasks, which each had 102 trials in their experimental phase (Ambrosi et al., 2016). Therefore, sustained use of endogenous cue-utilisation in the current study may have been influenced by the shorter time frame required to maintain this higher-order strategy, compared to the previous chapter.

To assess whether exposure to a singleton distracter influenced cue-use in Chapter 3 relative to the current chapter, I conducted an exploratory analysis. I selected the first 48 trials of the Mostly Predictive block and the Baseline block in Chapter 3 to compare cue-use (on singleton-absent trials) to the current chapter, whilst controlling for differences in block length. If exposure to a singleton distracter influenced cue-use, it was expected that five- to six-year-olds would have poorer cue-use in Chapter 3 than the current chapter; this would be further demonstrated by age-differences (5-6 vs 9-11 years) in Chapter 3 but not in the current chapter. For accuracy, the findings showed that nine- to 11-year-olds in Chapter 3 had poorer accuracy on invalid trials relative to neutral and valid trials but these differences were non-significant for five- to six-year-olds in Chapter 3 and both age-groups in the current chapter. This is suggestive of age-differences in Chapter 3 but not in the current chapter. For response time, no significant difference in cue-use was found between chapters, which suggests cue benefits (valid vs neutral) and cue costs (invalid vs neutral) did not differ between both studies. Rather, participants in the current chapter had generally slower responses to those in Chapter 3. This suggests that exposure to the singleton distracter in Chapter 3 did not influence cue-use in five- to six-year-olds.

That being said, the Cue Validity x Chapter interaction for response time approached but did not meet significance (p = .014). The direction of this result could have suggested greater cue-use in the current chapter than in Chapter 3 in both age-groups (*see means on page 136*). Alternatively, this result may not be an effect of Cue Validity but of overall cue predictiveness. Monitoring of the overall level of cue predictiveness across all block conditions in the current study and Chapter 3 may have influenced the formation of task-goals. Participants may have been more encouraged to maintain the cues in the current study as monitoring of the cue over the course of the study meant that they were considered a more reliable source of information overall. In Chapter 3, the overall predictiveness of the cue in guiding attention towards the target across all three block conditions (Mostly Predictive, Low Predictive & Baseline) was 33.33%. In contrast to this, the overall predictiveness of the cue in the current study (Always Predictive, Mostly Predictive, Baseline) was 55.56%. It is possible that all children were more encouraged to maintain the cues in the current study relative to Chapter 3, as the cue was generally more reliable across the experiment, albeit at chance levels. Children may have considered the cue to be a more useful source of information, thereby affecting the implicit task-goal set within each block condition. This conclusion is tentative and will be further reviewed once data collection has been completed.

It is important to note that the comparison of cue-use between Chapter 3 and the current chapter was exploratory and post-hoc. Despite controlling for block length in this analysis, differences between the studies still remained. In addition to differences in overall cue predictiveness, differences in counterbalancing remained as stimuli was fully counterbalanced in the current chapter but not for the first 48 trials of each block in Chapter 3. Thus, future research should aim to directly assess the influence of singleton distracter exposure on cue-use in childhood.

Future Directions

As previously discussed, the exclusion of the singleton distracter could explain the differences in the findings for five- to six-year-olds shown here, compared to the previous study in Chapter 3. However, to accurately assess this claim, one would need to directly compare cue-utilisation whilst controlling for differences in the search-display and the cued items. Visual working memory has been highly regarded for its involvement in ensuring cue-maintenance in selective attention (Cohen, Sreenivasan & D’Esposito, 2014; Corbetta, Kincade & Schulman, 2002). Measures of this ability can be used to assess whether individual differences in working memory play a role in endogenous cue-utilisation in early-childhood. Evidence has shown that 10-

year-olds with high capacities behave adult-like in their maintenance of cued information, but the temporal dynamics of this process were slower to engage as well as longer relative to adults (Shimi et al., 2015). Others have measured the involvement of this skill by examining memory for items presented at target and singleton distracter locations (Arita et al., 2012; Gaspelin et al., 2015, 2017; Sawaki & Luck, 2010). This is argued to provide a greater depth of evidence concerning where attention was allocated in space and the level of which attentional capture, or lack thereof, engaged attention (Gaspelin & Luck, 2018). Overall, the relationship between visual working memory and attentional allocation is one which warrants further consideration in Cued Visual Search.

Limitations

It should be noted that I did not control for age-related differences in response times in the cue benefit and cue cost analyses. As expected, a main effect of Age-Group was found in these analyses which showed nine- to 11-year-olds to be generally faster than five- to six-year-olds. This is not considered a cause for concern as I did not find Age-Group to interact with any of the within-subject factors. In addition, the findings from the exploratory analysis with cueing ratios, which controlled for age-related differences in response times, support the results found in the cue cost analysis. Altogether, this suggests that the differences in general response times between age-groups did not play a large role in contributing to the cueing effects found between block conditions.

It is important to emphasise that the findings from the current chapter are based on an incomplete sample due to disruption caused by COVID-19[21]. As I powered for an interaction with Age-Group, it is possible that the non-significant Block x Age-Group interactions found for cue benefit and cue cost

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[21] I had powered for an interaction between Cue Validity (valid, neutral) x Age-Group (5-6, 9-11 years) using data from Wainwright and Bryson (2005), which showed 54 participants per age-group were required to attain power of .8 using an alpha criterion of .01.

in the current study is due to reduced power (η_p^2 ranged from .004 - .03 for predicted interaction terms in response time analyses). In addition, despite finding a significant cue cost on invalid trials in the Mostly Predictive block (vs valid trials in the same block and neutral trials), a cue benefit was not found for valid trials in the Mostly Predictive block (vs Always Predictive and neutral trials; p values equal to .017 and .01 respectively). But both of these comparisons had small-to-medium effect sizes (Cohen's d ranged from .34 - .37). Therefore, the conclusions concerning the role of metacognitive monitoring in the Always Predictive block and the lack of age-differences found in cue-utilisation are cautious and will be reviewed once data collection has been completed.

Conclusion

The current chapter aimed to examine the role of block predictiveness of cue-utilisation in children aged five to six and nine to 11. The results contrasted with Chapter 3 in showing a competent form of endogenous control has developed by early-childhood and, contrary to expectation, does not significantly differ from the more experienced strategy developed in nine- to 11-year-olds. This suggests that endogenous cue-utilisation can be encouraged by mostly predictive and always predictive contexts and this form of control remains relatively stable until mid-childhood (Dye & Bavelier, 2010; Hermens, 2018; Johnson et al., 2016; Landry et al., 2019). The possible reasonings for the differential results between chapters were discussed and provided additional factors to further consider cue-utilisation in early-childhood. To expand on our current understanding of endogenous control, one should question whether this process is used similarly (domain-general) or differently (domain-specific) in distinguished measures of attentional control in adulthood. This will provide a clearer depiction of this higher-order skill and ease the comparison and interpretation between the different measures.

Chapter 6: Age-Related Changes in Endogenous Control: A Comparison of Cued Visual Search and the AX-CPT

Abstract

My study of endogenous control thus far has shown that it is capable of guiding attention at an early point in time. It is questionable however, whether this skill changes in older adulthood and if it is used similarly in different measures of this process. The current chapter compared endogenous cue-utilisation in Young and Older Adults using the Cued Visual Search task and the AX-CPT; a highly used measure in the cognitive control literature. The findings showed that both age-groups used endogenous control in both the Cued Visual Search task (Mostly Predictive block) and the AX-CPT; suggesting endogenous control does not decline into an exogenous strategy in older adulthood. Contrary to predictions, cue-use in both of these measures were not related to one another and age failed to moderate this relationship. In addition, endogenous cue-utilisation failed to reduce attentional capture in the Cued Visual Search task in both Young and Older Adults; replicating the pattern of results found in Chapter 3. Altogether, the findings suggest that endogenous control is preserved in seniority and may be a domain-specific process which is task-dependent. The results emphasise the importance for comparing measurements of this skill. The future directions for these findings will be discussed.

Introduction

The current understanding of endogenous control which has been explored thus far, suggests that this ability improves with increasing age. Specifically, the current findings have shown that children aged between five and six years have acquired an immature form of endogenous control which may lead to a cognitive trade-off with the ability to inhibit impinging distractions. This immature form of endogenous control which allows children to maintain information at an early point in processing, may have less control over the type of information that is maintained. Suggesting that early forms of this skill may be less effective for guiding attention in situations where there is high distractibility. In addition to this, the findings from past chapters has shown that later forms of endogenous control between nine to 11 years, become adult-like as children in this age-group are able to effectively utilise this skill to guide attention in both distracting (Chapter 3) and non-distracting situations (Chapter 5). The use of endogenous cues have so far been shown to be insufficient for reducing attentional capture from a singleton distracter in both nine- to 11-year-olds and young adults (Chapter 3). It is less understood however, how the development of endogenous control tracks in older adulthood.

It was discussed in Chapter 1 that the use of endogenous control is said to decline into the main use of an exogenous form of control in aging populations (Paxton et al., 2008; Zanto et al., 2010). However, findings from non-spatial (*AX-Continuous Performance Task:* Braver et al., 2009; Braver, Satpute, Rush, Racine & Barch, 2005; Paxton et al., 2008) and spatial (*Cued Visual Search:* Hahn & Buttacio, 2018; Müller-Oehring, Schulte, Rohlfing, Pfefferbaum & Sullivan, 2013) paradigms of endogenous control have often contested one another. This has made it difficult to draw comparisons between findings. It is therefore possible that endogenous control through early cue-utilisation, is not a generalised type of process but may be used differently depending on spatial and non-spatial computations for guiding attention (Gottlieb & Snyder, 2010). The current chapter will discuss the relevant literature for understanding the changes in endogenous control in old age in the Cued Visual Search task and the AX-CPT, before presenting the method and findings for the present aims.

Research has argued that endogenous control becomes impaired in seniority and this may be linked to impaired frontal lobe recruitment (Braver et al., 2005, 2009; West, 2000). Aging can lead to a loss of cells in anterior as well as posterior regions of the brain, but this reduction is particularly focused in the frontal lobe (Kramer, Humphrey, Larish, Logan & Strayer, 1994). As a consequence, older adults may be at a particular disadvantage recruiting processes which heavily rely on frontal activations, such as working memory, inhibition and attentional control (Braver et al., 2009; Reuter-Lorenz et al., 2000; Salthouse et al., 2003; West, 2000). Diffusion tensor imaging has shown that the reduced integrity in white matter within the prefrontal regions was associated with poorer working memory performance, but impairment in the posterior parietal regions corresponded with poorer inhibition and enhanced switching costs (Kennedy & Raz, 2009). In visual search, older adults had enhanced prefrontal P300 activity during exogenous, and particularly in endogenous, search for the target (Li et al., 2013). At the same time, overrecruitment of the prefrontal regions in older adulthood is often suggested to be a compensatory mechanism for the impairments or reduced integrity in this area (Grady, 2008; Huang et al., 2012; Velanova, Lustig, Jacoby & Buckner, 2007). Altogether, the evidence suggests that the structure and recruitment of the prefrontal area changes with increasing age and as a result, may impact the use of endogenous control in older adulthood.

A number of experimental paradigms have been used to evidence the impaired use of endogenous control in older adults. Cued task-switching has shown that older adults experience larger switching costs (Czernochowski, 2014) and have enhanced activation of the prefrontal regions during switching but also non-switching trials compared to young adults (DiGirolamo et al., 2001). In addition, older adults experienced greater difficulty (i.e. slower response times, increased dorsolateral prefrontal activation) when required to inhibit the task-irrelevant word in favour of selectively attending to the colour of the word in the Stroop task (Milham et al., 2002). Overall, research suggests that older adults have a general deficit at maintaining task-goals and recruiting endogenous processes. Next, I will focus my discussion on two measures of endogenous control (AX-CPT & Cued Visual Search) which both assess task-goal maintenance to form an expectation about an upcoming target.

The AX-CPT is a variant of the Continuous Performance Task (CPT; Rosvold, Mirsky, Sarason, Bransome & Beck, 1956) and a measure of attentional (or cognitive) control which has been widely used across different populations (Braver, Gray & Burgess, 2007; Chatham et al., 2009; Hämmerer, et al., 2010). Earlier versions of this task present participants with a sequential display of letter stimuli. Participants are instructed to make a target-response when shown the cue “A”, followed by the probe “X” and a non-target response for derivative trials (BX, AY, BY). The proportions of these trials are manipulated to encourage processing of contextual information in a similar way to the Mostly Predictive block of the Cued Visual Search task. A larger proportion (60-70%) of AX trials are presented to encourage participants to form and maintain an active task-goal, which is to expect probe “X” to follow cue “A”. As a result, this task-goal can bias attention whereby maintenance of cue information can enable participants to make an anticipatory response to the probe (Gonthier, Macnamara, Chow, Conway & Braver, 2016).

Endogenous (or proactive) individuals are defined by their ability to maintain the early cue (“A” and “B”) to anticipate the probe; leading to greater difficulty (slower response times, poorer accuracy) on AY trials where they had prepared to make a target-response in reaction to the “A” cue. In contrast, performance is facilitated (faster response times, better accuracy) on BX trials as the early maintenance of the “B” cue allows participants to make an anticipatory non-target response. On the other hand, exogenous (or reactive) control is defined by participants’ inability to maintain cue information and so this form of control relies on the late “in-the-moment” processing of probe information (“X” and “Y”). Participants biased towards exogenous control have better performance on AY trials, but poorer performance on BX trials; the opposite pattern of results found in those biased towards endogenous control. Therefore, the AX-CPT is effective at disentangling endogenous and exogenous processes by assessing whether participants can use contextual information to maintain early cues to guide attention.

Studies which have used the AX-CPT with older adults have shown that this age-group has a *goal maintenance deficit* which leads them to recruit an exogenous (or reactive) form of control (Braver et al., 2001). Older adults are often shown to perform worse (i.e. slower response times, poorer accuracy) on BX trials compared to AY trials (Braver et al., 2007; Haarmann et al., 2005; Paxton et al., 2008). This suggests that older adults did not maintain the task-goal and as a result, they did not form an expectancy bias in response to the cue. This led to impaired performance on BX trials as they failed to inhibit the target-response but performance was *not* impaired on AY trials, as they did not have a strong tendency to expect “X” following cue “A”. Rather older adults tend to rely on processing probe information to reactivate the task-goal in the moment it is required. This is evidenced by their reduced activation in the lateral prefrontal regions during the cue-target delay period, but this is enhanced during probe presentation (Braver et al., 2009; Paxton et al., 2008). Therefore, older adults may have an impaired ability to maintain contextual task-goals which could reduce their ability to utilise task-relevant information, such as the cue, to anticipate an upcoming probe.

Conversely, there is mixed evidence surrounding this age-group in the AX-CPT. Some evidence has shown older adults performed endogenously, as they had slower response times and poorer accuracy on AY trials compared to BX trials (Hämmerer et al., 2010; Kray et al., 2015; Rush et al., 2006). To unpack this, research has questioned whether verbal labelling of the cue would promote proactive engagement in older adults by enhancing the salience and interpretation of this early information (Kray et al., 2015). Contrary to predictions, older adults engaged proactive control as effectively as young adults and, like young adults, they did not further benefit from verbal labelling of the cue. In a go/no-go variant of the AX-CPT where participants were required to withhold making a response on derivative trials (AY, BX & BY), ERP results showed older adults experienced difficulty on high conflict trials (AY) but were unaffected in building a Contingent Negative Variation expectation from cue-related processing (Hämmerer et al., 2010). Altogether, this research contrasts with previous findings using this task, as it indicates that endogenous maintenance of a task-goal and cue information is preserved in older adulthood.

In support of this claim, studies using the Cued Visual Search task have shown task-goal maintenance is unaffected by age in older adulthood. This is suggested by older adults' ability to learn about the predictability of the cue or the target (i.e. location associations) to form an implicit task-goal and bias attention (Howard, Howard, Dennis, Yankovich & Vaidya, 2004). In more complex situations, older adults experienced more difficulty locating the target than young adults, when the cue was associated with two target colours but search slopes did not vary with task complexity (i.e. they were efficient; Hahn & Buttacio, 2018). Suggesting that older adults are able to maintain a contextual task-goal to facilitate performance when later searching for a target.

In addition, the ability to encode and maintain cues to bias attention in Cued Visual Search, is said to be age-invariant in some search tasks (Humphrey & Kramer, 1997). When searching for a featural target (i.e. a target defined by one unique feature), older adults' ability to utilise mostly predictive cues is as robust as young adults; often shown by non-significant differences in behavioural performance (Humphrey & Kramer, 1997; Greenwood & Parasuraman, 2004; Madden et al., 2004; Madden & Plude, 1993). Age-equivalence effects at the behavioural level may be resultant from differences at the cortical level, as Madden (2007) found older adults had increased activity in the frontal eye fields and superior parietal cortex which correlated with their behavioural performance. This suggests that older adults may compensate for neural deficits via overrecruitment of these regions, which emphasises the age-differences found at the cortical level but not at the behavioural level.

In general, there are mixed findings concerning age-related changes in endogenous control during adulthood. Studies using the AX-CPT has shown frontal decline in older adults leads this age-group to mainly rely on exogenous control (Braver et al., 2005, 2009; Haarman et al., 2005; Paxton et al., 2008). However, others using variants of this paradigm have opposed this (Hammerer et al., 2010; Kray et al., 2015; Rush et al., 2006). Indeed, studies using the Cued Visual Search task have also shown that endogenous control is preserved at the behavioural level in old age (Humphrey & Kramer, 1997; Greenwood & Parasuraman, 2004; Madden, 2007). This variability in behavioural findings is concerning as it is assumed that both the AX-CPT and the Cued Visual Search task measure the same underlying construct. This raises the question concerning whether endogenous control is used similarly or differently in these measures. Next, I will compare both of these methods as well as question whether endogenous performance in both of these tasks overlap.

Comparing AX-CPT & Cued Visual Search

The Cued Visual Search task and the AX-CPT both measure endogenous performance by assessing cue-maintenance for building an expectation for an upcoming target item. In Cued Visual Search, this is achieved by manipulating the proportion of valid to invalid trials to encourage cue-maintenance which is evidenced by slower response times on invalid, relative to valid trials. Similarly, in the AX-CPT a larger proportion of AX trials encourages cue-maintenance by biasing attention to expect probe “X” to follow after processing cue “A”. This is evidenced by greater difficulty (slower response times, poorer accuracy) on AY trials relative to BX trials. AY trials can be defined as invalid as the cue “A” incorrectly biases attention to prepare to make a target response. AX and BX trials can be defined as valid as the cue directly biases attention to either expect an “X” probe and therefore make a target response (AX trials) or prepare to make a non-target response at an early point in processing (BX trials; Gonthier et al., 2019; Lorsbach & Reimer, 2010). Therefore, the behavioural profiles of endogenous control are defined similarly in Cued Visual Search and the AX-CPT.

Endogenous control has been investigated using different experimental paradigms without comparing performance between these measures, which makes it difficult to draw comparisons between the findings. Some evidence has shown endogenous performance in the AX-CPT to be significantly predicted by endogenous performance in the Track-It and cued task-switching measures in children aged five to six (Doebel et al., 2017). This suggests that endogenous control is a domain-general process as it was used similarly in different measures of this skill. It is difficult to generalise these findings to older age-groups who have more experienced forms of attentional control. In support of this, opposing findings from a recent study showed that older adults who had trained in cued task-switching had improved switching performance but this training failed to transfer to the AX-CPT (Kray, Ferdinand & Stenger, 2020). To my knowledge, it is scarcely known whether performance in the AX-CPT and the Cued Visual Search task is related and whether this relationship changes with age. Therefore, it is important to gain a deeper understanding of this higher-order skill by assessing whether endogenous performance is used similarly in different measures.

Attentional Capture

A secondary question in this chapter, is to assess whether the use of endogenous control to reduce attentional capture is influenced by age in adulthood. Some research has shown that older adults experience an Inhibition Deficit (Lustig, Hasher & Zacks, 2007), which was reflected by reduced distracter suppression (ERP N170; face-sensory waveform) and better memory for to-be-suppressed faces in older adults, compared to young adults (Clapp & Gazzaley, 2012; Zanto et al., 2010). In correspondence with this, older adults were worse at using an early arrow cue to inhibit an onset-distracter; specifically, they were worse at modulating and recovering from capture relative to young adults (Iarocci et al., 2009). This evidence suggests that older adults are unable to utilise a maintained task-goal to inhibit task-irrelevant signals from impinging on attention.

However, others have demonstrated opposing findings with regard to the role of aging on attentional suppression. In visual search, age-equivalence effects were found in the ability to suppress a colour-singleton, after controlling for generalised slowing effects (Costello et al., 2010). Further evidence has shown preservation of top-down oculomotor systems in aging (Kramer, Hahn, Irwin & Theeuwes, 1999). In this study, participants were required to suppress attentional capture induced by an onset-distracter, using a similar method to Iarocci et al. (2009) described above. The findings showed that older adults were as effective as young adults to detect the featural target and ignore the distracter. This was reflected in their saccadic-movements, as both age-groups had similar saccadic latencies but older adults had reduced saccadic accuracies (i.e. they made more fixations). A similar finding was also shown in the capture contingency paradigm, as both young and older adults deployed attention towards relevant pre-cues (i.e. contained a target defining feature; Juola et al., 2000; Pratt & Bellomo, 1999). Both age-groups were also able to use a task-goal to suppress capture towards an abrupt-onset distracter (Lien et al., 2011). Thus suggesting that the ability to down-regulate a salient distraction is retained in older adulthood. To my knowledge, it is less understood whether early cue maintenance is able to override an attentional response towards a salient distracter when it is in direct competition with the target.

The Current Study

The current chapter aimed to investigate age-related changes in endogenous control in older adulthood using two experimental paradigms. I asked young and older adults to complete the Cued Visual Search task outlined in Chapter 3 (Mostly Predictive and Baseline blocks only) and compared this measure to the child-adapted AX-CPT used in Gonthier et al. (2019; originally established by Lucenet & Blaye, 2014). Minor changes were made to the Cued Visual Search task to ensure the method sequence replicates the AX-CPT used in this study (*see Methods section*).

This study assessed four key aims outlined in *Table 6.1* overleaf. Cue-utilisation performance was assessed individually in each task (Aim 1) before I considered the predictive relationship between the measures and whether age played a moderating role (Aim 2; main aim). I also questioned if endogenous cues could override attentional capture in the Cued Visual Search task and whether there were age differences related to this finding (Aim 3). Analytical Chapter 4 showed cross-colour priming effects could not explain the differences found between assigned trials in the Baseline block. I used a colour categorisation task to measure individual differences in cross-colour discriminability. It was included in my analysis for Aim 2 as a *control measure* for any possible cross-colour priming effects in cue-utilisation.

Cue-utilisation was defined by significant differences in performance between invalid and valid trials (cueing ratio scores > 1) in the Mostly Predictive block, relative to the Baseline block of the Cued Visual Search task. In AX-CPT, this was reflected by differences in behavioural performance on AY relative to BX trials (Proactive Behavioural Index scores > 0; *see Results*).

For **Aim 1**, it is predicted that cue-maintenance will heighten with increasing age. Specifically, I expected that young adults will utilise the cues endogenously in both the AX-CPT and the Cued Visual Search task. Two predictions were made for older adults. An age-related decline would predict that cue-utilisation significantly reduces in older adults compared to young adults (Braver et al., 2009; Paxton et al., 2008). Conversely, the retainment of this skill would predict non-significant differences in cue-utilisation between

Table 6.1. Three aims to assess age-related changes in cue-utilisation and distraction in the AX-CPT and Cued Visual Search paradigms.

	Cued Visual Search	*AX-CPT*
Aim 1	To understand if there are age-related changes in cue-utilisation	
Aim 2	To assess whether cue-utilisation in the Cued Visual Search task and the AX-CPT is related and whether age moderates this relationship	
Aim 3	To assess whether early cue information can reduce attentional capture from a singleton distracter	

young and older adults (Greenwood & Parasuraman, 2004; Kray et al., 2015). For **Aim 2 (main aim)**, if both experimental paradigms measure the same underlying mechanisms, cue-maintenance in the AX-CPT was expected to predict cueing in the Mostly Predictive block of the Cued Visual Search task. Greater variance was expected to be explained when taking into account age moderating effects. If there were cross-colour priming effects, it was predicted that cross-colour discrimination would explain a significant proportion of cue-utilisation; whereby those who were worse at discriminating between different categorical colours would experience less cue-utilisation in the Mostly Predictive block. **Aim 3** expected that if cue-maintenance influenced attentional capture, distraction caused by the singleton distracter would be reduced on valid trials but increased on invalid trials in the Mostly Predictive block, relative to Baseline. Based on previous research (Iarocci et al., 2009; Gaspar & McDonald, 2014), this pattern of results was expected to occur in young adults and might have been retained in older adults (Lien et al., 2011).

Method

Mitigation of COVID-19

The above aims for the current study were originally intended to be examined across the lifespan with five age-groups (5-6, 7-8, 9-11, 18-25 & 60+ years). The hypotheses and analyses for the intended study were pre-registered on the Open Science Framework (*see Appendix 6.1*). A power analysis using G*Power version 3.1.9.2 (Faul, Erdfelder, Buchner & Lang, 2009) was conducted for Aim 2 (main aim) based on the pre-registered design. I planned to use a multiple regression analysis to assess this aim (*see Results*). Based on previous research which has compared the version of the AX-CPT used in the current study to other experimental paradigms (Track-It paradigm; Doebel, et al., 2017), I powered for a small to medium effect size (Cohen's *d* = .10) for my model's (nine predictor variables) R^2 to deviate from 0 using an alpha criterion of .01. This found that a power of .9 is attained with a total sample size of 273 participants. I aimed to recruit 54-55 participants per age-group.

Data collection for Older Adults took place from July to December 2019 and for Young Adults, this took place from October 2019 to April 2020. I was scheduled to begin data collection of child participants at a local primary school in January 2020, however due to staff shortages at the time I was unable to commence with the placement. Despite this, I had organised to recruit child participants by inviting them and a parent/carer to the university on weekends to complete the study. This was approved by the School of Psychology Operations Managers following detailed risk assessments and safety procedures. This method was used to recruit child participants in Chapter 5 and due to its success, I had planned to achieve data collection of child participants for the current study using a dual-approach: 1) university invite on weekends and 2) school data collection. Advertising for university invite took place via social media (local parent Facebook groups) and two local schools had consented to distribute letters to students. My understanding was that this approach would reduce the pressure on schools for acquiring large sample sizes, as well as make more use of my time. When I began using this approach, I was able to recruit four child participants (5-6 years: N = 1; 9-11 years: N = 3) and had successfully recruited a local infants school. I was scheduled to begin data collection in March 2020, however due to COVID-19 I discontinued all in-person testing. I mitigated the impact on my research by converting the intended lifespan study into an online study (*see Methods, Online Testing*). Online data collection is still on-going and so the data has not been analysed and will not be reported here. The current chapter will focus on the predictions assessing age-related changes between young and older adulthood with the existing dataset collected in-person.

Participants

85 participants from two age-groups (18-25, 60-84 years) completed this study (*see Table 6.2*) after exclusion. One participant in the Young Adult

age-group was excluded as they reported to have been formally diagnosed with eye floaters and reported to see more prominently in the white background of the task. No participants reported to have had been formally diagnosed with a developmental disorder (ASD/ADHD) or any form of colour blindness. Young Adults were recruited from the University of Nottingham School of Psychology (undergraduates: N = 41; postgraduate: N = 1). Older Adults were recruited by friend referral (N = 2) or from the university's participant database (N = 40) which consists of community adult samples from Nottinghamshire. All participants provided informed consent to take part and were provided with an inconvenience allowance to compensate their time in the form of either a course credit or £10. This study was approved by the University of Nottingham School of Psychology Ethics Committee.

Table 6.2. Participant demographic information.

	Young Adults	*Older Adults*
N	43	42
M age (SD) (years, months)	19.34 (1.60)	10.43 (0.56)
Age range (years, months)	18.80 – 25.92	9.50 – 11.50
Gender Identity (m : f)	11.63% : 88.37%	42.86% : 57.14%
Ethnicity	62.79% White, 16.28% South Asian, 16.28% Chinese, 2.33% Black, 2.33% Mixed Ethnic Groups	100% White
Bilingual	48.84%	7.14%

Note: M = mean; SD = standard deviation; m = male; f = female.

Design

A mixed design was used as all participants from two age-groups (Young, Older Adults) were asked to complete three different experimental paradigms: 1) Cued Visual Search (two block conditions), 2) AX-CPT (one block condition) and 3) Colour Categorisation (six block conditions). The details and procedure concerning each paradigm will be discussed in turn.

AX-CPT

Stimuli

The AX-CPT used in the current study was a child-adapted measure which was originally produced by Lucenet and Blaye (2014), with minor adaptations made in the latest version by Gonthier et al. (2019) which was selected for this study[22]. This task is similar to previous versions of this task presented to adults (Braver et al., 2007; Braver et al., 2009; Redick, 2014), but participants were presented with animal rather than letter stimuli. There were 14 different animals presented throughout the task (hen, cat, lion, horse, elephant, giraffe, crocodile, mouse, rabbit, sheep, snake, turtle, snail & cow).

On each trial, participants were first presented with a fixation cross in black Courier font (1.47°) followed by the Cue-Display which presented an animal (4.90° width x 4.90° length) for 1000ms in the centre of the screen (*see Figure 6.1 overleaf*). The Cue-Probe Delay consisted of the fixation cross for 1500ms, before the presentation of the Probe-Display which consisted of an animal of the same size as the Cue-Display and two red and green coloured circles located on the left and right side of the display. Specifically, they were both 8.13° on the *x-axis* and 6.52° on the *y-axis* away from the centre of the screen. The location of the red and green circles were contingent on hand dominance and served to remind participants to make a response as well as make it easier to separate the cue and the probe, which was highlighted in the instructions (Gonthier et al., 2019). The Probe-Display remained on-screen until a response was made or the response time deadline was exceeded (set to 6000ms in the practice phase). Auditory feedback was provided for 500ms for all responses. If participants failed to make a response within the timeframe of the response time deadline, a ticking clock (4.90° width x 4.90° length) was presented 0.82° above fixation for 500ms.

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[22] The AX-CPT was adapted from E-Prime software (Schneider, Eschman & Zuccolotto, 2002) into PsychoPy software (Peirce et al., 2019). Special thanks to Dr Joanna Lucenet for her correspondence and sharing of resources in making the replication of this task successful.

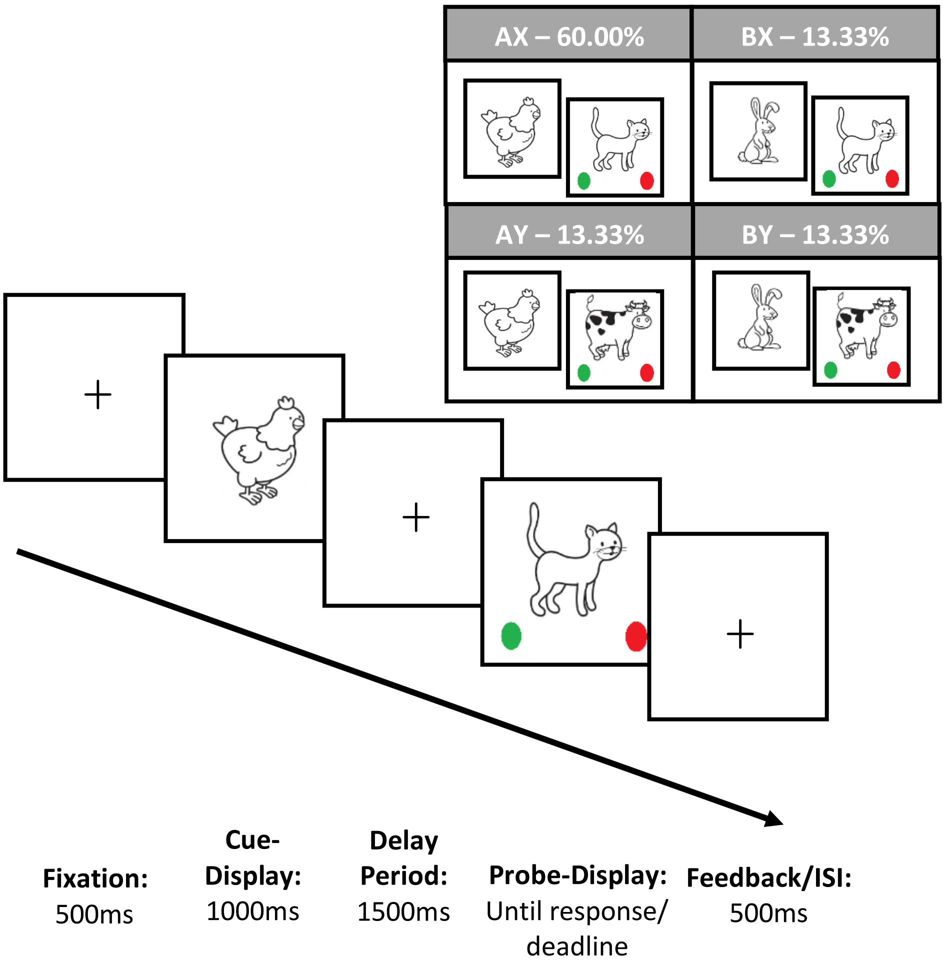

Figure 6.1. Schematic representation of the AX-CPT replicated by Gonthier et al. (2019). The trial sequence depicts an AX (hen-cat) trial. Examples and proportions of BX (rabbit-cat), AY (hen-cow) and BY (rabbit-cow) trials are included. All stimuli rights: Lucenet & Blaye (2014).

Task Procedure

The instructions provided to all participants was replicated from Lucenet and Blaye (2014) and Gonthier et al. (2019). Participants were instructed that animals were racing and that they would always see two animals running together in each race (cue then probe). The key instruction highlighted that if they saw a hen and then a cat, they needed to press the green key with their dominant hand, otherwise they needed to press the red key with their non-dominant hand. They were instructed to make a response as fast and accurately as they could. Stickers in accordance with hand dominance and colour were placed on the “z” and the “/” keys.

Participants were first provided with a demonstration of eight trials by the researcher. The researcher verbally labelled the animals as they were presented (i.e. “it’s a hen and then a cat, so I press the green key”), as well as demonstrated the three auditory feedback tones for accurate, inaccurate and too slow responses. They then completed 16 practice trials. Using the same criteria as in previous chapters, if a participant made three or more inaccurate responses, they were asked to repeat the practice phase. This phase could be repeated up to two times, before they were thanked for taking part. No participants met this criterion.

The experimental phase consisted of 90 trials separated into 3 blocks (60% AX, 13.3% BX, 13.3% AY, 13.3% BY trials). To control for order effects in trial sequences (Chatham et al., 2009), a semirandom order was applied to the presentation of animals and trial types following the same rules as Gonthier et al. (2019). Each block of 30 trials started with 2 AX trials and consecutive sequences of 1 AX, 2 AX and 3 AX trials occurred three times each. In addition, trials which required the same response never occurred more than three times in a row (e.g. AX, AX, AX or BX, BY, AY etc.). Lastly, all derivative trials (AY, BX & BY) were all equally likely to follow an AX trial. The counterbalancing for intertrial order effects was completed using a python script I created for each individual participant. This ensured that there were different cue-probe pairings on derivative trials as the animals corresponding to cue “B” and probe “Y” stimuli were randomly selected from the list of 12 animals, whilst also ensuring trial sequences were varied and in accordance with the rules highlighted above.

As previously mentioned, a response time deadline was created to encourage participants to stay on-task. This was calculated by averaging the response times from all previous blocks of trials + 4SD[23]. For the first block of trials, this deadline was calculated using data from the practice phase. This

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[23] This response time deadline was replicated from Gonthier et al. (2019) who calculated average response time from previous blocks + 1SD. The standard deviation was increased to 4SD in my calculation to compensate the faster response times of adults and reduce the likelihood of over-filtering the data.

deadline was updated at each break period (two break periods), using data from all previously completed practice and experimental trials.

Cued Visual Search

The design and method for the Cued Visual Search task is consistent with Chapter 3, but differed in the following ways:

1. Participants no longer completed the Low Predictive block and so the within-subjects factor Block had two levels (Mostly Predictive block – 66.67% of trials were valid, 33.33% of trials were invalid; Baseline block – 100% of trials were neutral).
2. In Chapters 3 and 5, participants were presented with the Cue-Display for 300ms, immediately followed by the Search-Display. In the current study, the Cue-Display was presented for 1000ms, followed by a Cue-Target Delay (interstimulus interval) which presented a fixation cross for 1500ms and finally the Search-Display. This change to the temporal characteristics of the cue was introduced to replicate the stimulus timings in the replicated AX-CPT (Gonthier et al., 2019). Also, past research has shown that longer stimulus onset asynchrony (SOA) periods related to cue information yields larger cue-utilisation in Cued Visual Search, as this provides participants with more time to process, prepare and anticipate the upcoming target; a finding which is mimicked across the lifespan (Iarocci et al., 2009; Wainwright & Bryson, 2005).
3. The Search-Display was presented to participants until they made a response in Chapters 3 and 5. In the current study, a deadline to make a response was calculated for each participant based on average response times from previously completed trials using the same calculation described for the AX-CPT[24]. This change was introduced to mimic the method of the AX-CPT, as well as encourage participants to make a

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[24] The response time deadline for the first block of trials used data from the cue-practice phase. The deadline was updated three times (at each break period) during the experimental trials.

response as fast and accurately as they could whilst accounting for individual differences in response times throughout each task.

4. Auditory feedback was provided for all responses, rather than presenting visual feedback for inaccurate responses only.
5. I demonstrated nine trials of the Response Practice phase (no cue) and nine trials of the Cue Practice phase to participants to explain the task and auditory feedback tones, before they completed these phases themselves.

Colour Categorisation

Stimuli

A control measure to assess cross-colour priming effects in the Cued Visual Search task was derived. This task aimed to measure individual differences in the ability to discriminate between different categorical colours. A three interval forced-choice task was used where participants were asked to make judgements to organise coloured circles into boxes. Participants completed six blocks of 15 trials where coloured circles ranged between two colours (blue-green, blue-pink, pink-green, yellow-blue, yellow-green & yellow-pink). The physical colours (termed “experimental colours”) used in the Cued Visual Search task were presented in each block condition (*see Figure 6.2 overleaf*).

To assess discriminability, the hue of the coloured circles gradually changed from one categorical colour to another. The RGB colour space (ranging from 0 to 1; where 0 = minimum deviation from grey and 1 = maximum deviation from grey) was used to make changes to hue based on the redness, greenness and blueness colour channels[25]. For instance, in the blue-to-green condition, redness decreased (by .0228), greenness increased (by .015) and blueness decreased (by .0935) in their respective channels on each trial. To compute the extent to which each colour channel changed on each trial, the difference between the experimental blue and experimental

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[25] This scale also matched the colour calibration measurement which corrected the output for the red, green and blue colour guns based on the overall luminance of the monitor (*see page 67*).

green RGB values was calculated and divided by 10 to create a gradual shift between the colours. This procedure was replicated for all colour block conditions (*see Appendix 6.2*). Trials in each condition were presented randomly to participants.

On each trial, a fixation cross in black Arial font (0.41°) was presented followed by a coloured circle (8.13° width x 8.13° length; cosine mask with fringe width 0.59°) in the centre of the screen along with two boxes which appeared at the bottom left- and right-side of the screen (*see Figure 6.2*). The boxes were both 8.13° on the *x-axis* and 6.52° on the *y- axis* away from the centre of the screen. They included the categorical names which the participants needed to organise the colours. Judgement responses were

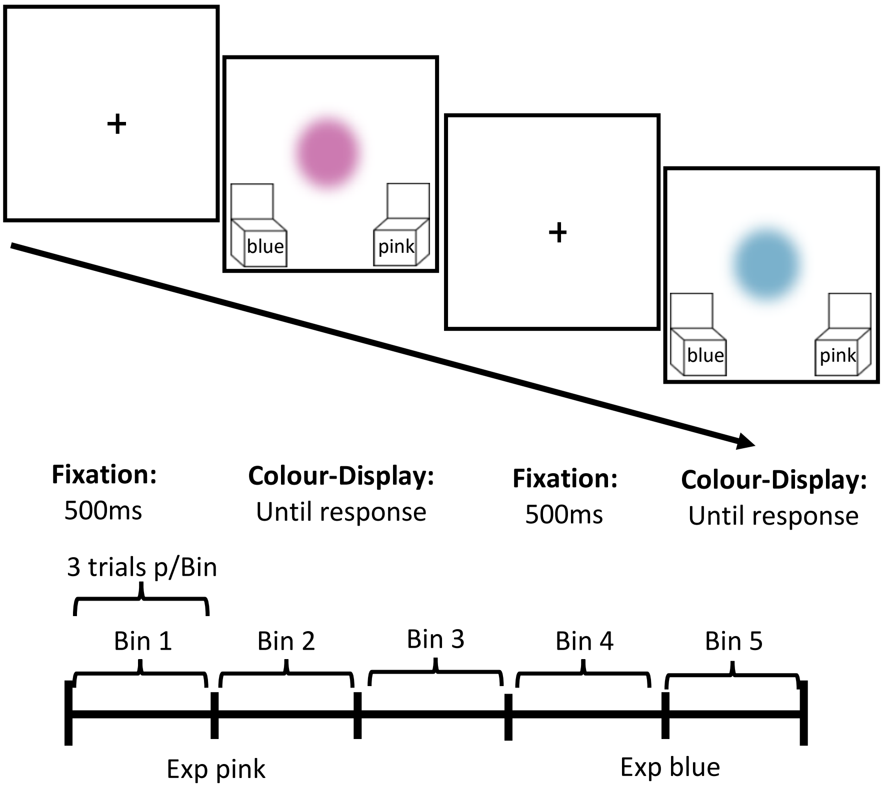

Figure 6.2. Schematic representation of the pink-blue block condition consisting of 15 trials. Top: two trial sequence of fixation and colour-display. Bottom: of the 15 trials in a block condition, there were five bins; each bin consisted of 3 trials. Responses in each bin were averaged following numerical recoding (e.g. 0 = pink, 1 = blue, 0.5 = neither category).

recorded via key-press which subsequently ended the trial (“c” = pink, “v” = green, “b” = blue, “n” = yellow; letter stickers were placed on top of keys). Participants were instructed that if they felt the circle did not fit in either of the categories in any given block, they could press the “g” key to reflect this judgement. It was emphasised that they should not rely on this response and they were reminded of this throughout the task. If participants made this type of response, they were asked to say the corresponding colour category out-loud which the researcher recorded. This third response choice was provided based on piloting of this study with older adults at a one-day public engagement event (University of Nottingham Silver Scientist) whereby all five participants who completed the task expressed difficulty with the instructions on “interval trials” (Bins 2-4). The inclusion of an uncertainty response is argued to improve the fit of the psychometric function applied to the data (Strasburger, 2001).

Task Procedure

Participants were invited to complete a colour sorting task where they would see a coloured circle which they needed to sort into one of two boxes. They were instructed, using an example, that they were *not* being asked to judge the *colour* of the circle but rather to judge whether the circle appeared *more similar* to one category relative to another (i.e. “you’re not being asked is this circle pink, but rather do you think this circle looks *more* pink or *more* blue”).

Responses where the named colour was a synonym for one of the categories in this task according to Kelly and Judd (1955) and Mojsilovic (2004) were recoded. Seven named colours were recoded but seven different colours belonged to their own category and so were defined as fitting into neither category (*see Appendix 6.2*). Following this, all responses were coded as either “1”, “0” or “0.5” to demonstrate changes in judgement. For instance, in the blue-green block, “blue” responses were coded as 1, “green” responses were coded as 0 and neither category responses were coded as 0.5. The responses in each block condition (15 trials) were averaged into five bins (1 bin = 3 trials). All coloured circles in each block were presented randomly. The order of the block conditions was counterbalanced between participants. The task took approximately five minutes to complete.

Apparatus

All stimuli were presented on the same monitor and keyboard used in previous Chapters 3 and 5. Unlike the previous chapters, which mirrored stimuli from a MacBook Pro 2 laptop, a Mac mini 3.1 processor was used to present the visual stimuli at a viewing distance of 70cm. PsychoPy 2 version 1.85 (Peirce et al., 2019) was used to present all of the tasks and create all stimuli in the Cued Visual Search task and the Colour Categorisation task[26].

Experimental Procedure

Participants were invited to the university to complete the experiment in a darkened noise-controlled lab. All participants were asked to complete the Colour Categorisation task (5mins) first to control for colour exposure effects, as research has shown that discriminability judgements are influenced by exposure to colour stimuli during experimentation (Martinovic et al., 2018). Following this, the order of the two block conditions of the Cued Visual Search task (15-20mins per block) and the AX-CPT (10-15mins) were counterbalanced between participants. Within and between each task, participants were provided with break periods.

Online Tasks

To mitigate the disruption caused by COVID-19 on the current study, I recreated all three experimental paradigms described above using online Pavlovia software version 2020.1.2 (Peirce et al., 2019). To confirm, data collection from this online version of the study is still ongoing and so the data

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[26] All image stimuli presented in the AX-CPT were shared by Dr Joanna Lucenet. The platform for which this stimuli was originally created is not known.

will not be reported in this chapter. The purpose of including this information is to demonstrate how the impact of COVID-19 on my research was mitigated as well as demonstrate the future direction for the intended lifespan approach for this study.

Online data collection meant participants were completing the task using different sized monitors. Therefore, the absolute sizes, location and luminance of the stimuli is likely to differ between participants, however for the former characteristics, height units were used to display the visual stimuli based on a scaled proportion of any given computer or laptop monitor. All colour visual stimuli in the Cued Visual Search task and Colour Categorisation task were recreated as images using PsychoPy 3 version 1.85 (Peirce et al., 2019). An alpha channel of 175 (where 0 is transparent and 255 is opaque) was applied to all colour stimuli to manipulate the transparency of the colour channels so the colours appeared similar to the lab-based stimuli and were also categorically different from one another. This method was an approximation for colour appearance and led to the change of the colour category "yellow" to "brown" in the Colour Categorisation task.

Instructions were provided to participants via written words (Colour Categorisation) as well as via a video demonstration of the tasks (Cued Visual Search & AX-CPT). Order counterbalancing of the Cued Visual Search task was approximate as it was coded by asking participants to complete the Mostly Predictive block first if their month of birth was between January to June or they would complete the Baseline block first for all remaining months. Intertrial counterbalancing in the AX-CPT was still upheld, as a stimulus input file was randomly selected from a pool of 25 input files created using a python script. To see the online tasks, the links are provided. Please use a Google Chrome internet browser to view the tasks:

1. Colour Categorisation: https://run.pavlovia.org/Ruman/dory-bubble-sort/html

2. Cued Visual Search – Block 1: https://run.pavlovia.org/Ruman/finding-dory-game/html
3. Cued Visual Search – Block 2: https://run.pavlovia.org/Ruman/finding-dory-level-2/html
4. AX-CPT: https://run.pavlovia.org/Ruman/animal-race-game/html

Data collection took place via an online public engagement event (University of Nottingham Summer Scientist Online) throughout August and October 2020. This presented all tasks as games for children aged 4-16 years to take part in and were compensated for their time in the form of a virtual token presented on a scoreboard. Data collection was also targeted at schools across England. I collaborated with another PhD student who was conducting research with children, to ask headteachers to distribute e-letters or include information in their newsletter concerning our online studies to parents who have children in years 1 to 6. Both approaches were successful as I was able to attain quality data from children who completed all conditions of the tasks (Summer Scientist Online: N = 17; Schools: N = 41 from eight different schools). Data collection of young adults via Sona Research Participation Scheme (N = 10) and for children via school recruitment is still on-going.

Results

Data Processing

The data from in-person data collection with Young and Older Adults was filtered following the same steps taken in previous Chapters 3 and 5. For both the Cued Visual Search task and the AX-CPT, the first trial of each block condition as well as the first trial following a break period were removed from the data (Cued Visual Search: 2.72%; AX-CPT: 3.20 % data removal). Outlier trials (response times and accuracy) were removed from the dataset whilst participants completed the task, whereby trials were timed out if participant's time to make a response exceeded the response time deadline. This led to the removal of .61% of trials in the Cued Visual Search task (Young Adults: .25%;

Older Adults: .36%) and 1.25% of trials in the AX-CPT (Young Adults: .50%; Older Adults: .76%). Trials where the singleton distracter was presented in the same quadrant as the target were removed from the Cued Visual Search dataset (8.29% data removal). Inaccurate trials were removed from response time analyses.

Outlying participants were analysed by calculating three Mahalanobis Distance assessments for each participant within each age-group. I calculated separate Mahalanobis Distances for each participant across median response times and mean accuracy data in: 1) the Cued Visual Search task, 2) the AX-CPT and 3) across all predictor variables (except the dummy and interaction term)[27] and the outcome variable inputted into the multiple linear regression analysis. No multivariate outliers were found in the Cued Visual Search task or regression variables. However, two outlying participants were found in the AX-CPT (cumulative probability < .001). Closer inspection of these participants showed that accuracy for one participant (OA12; older adult) on BX trials was below chance levels, whereas the accuracy for the second participant (YA24; young adult) on BY trials was above chance levels, but it was reduced relative to all other participants in their age-group. To ensure consistency across the analyses, both participants were excluded from all further analyses reducing the final sample size to N = 83 (young adults: N = 42; older adults: N = 41).

Consistent with Chapter 5, a conservative alpha criterion was used where *p* must be less than .01 to be classed as significant. For any significant interaction, simple main effects analysis was conducted using Bonferroni correction.

Analysis

This study investigated four aims in three experimental paradigms for both Young and Older Adults. The analyses for Aim 1 assessed age-differences

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[27] The dummy variable and interaction term predictor were excluded from the multivariate outlier analysis, as this analysis was conducted separately for each age-group. The main measure of cue-utilisation in the AX-CPT (Proactive Behavioural Index in response times) had been inputted into this analysis.

in cue-utilisation in the Cued Visual Search task and the AX-CPT. Aim 2 used a multiple linear regression analysis which included an interaction term to understand whether age moderated the predictive relationship in cue-utilisation between the Cued Visual Search task and the AX-CPT; a similar approach was also used in Chapter 3 to understand moderation effects between age-groups. For Aim 3, the influence of cue-utilisation on attentional capture was assessed in the Cued Visual Search using the same analytical approach used in Chapter 3. I also conducted an exploratory analysis to consider the predictive relationship between maintenance (cueing ratios) and inhibition (distraction ratios) abilities in the Cued Visual Search task; replicating the analysis in Chapter 3. Lastly, I examined individual differences in colour discriminability as a control measure for cue-utilisation in the Mostly Predictive block and so, it was inputted as a predictor variable in the multiple linear regression analysis described above. I further explored whether colour discriminability can explain differences in the Baseline block.

Aim 1: *Cue-Utilisation*

Cued Visual Search

If participants have developed endogenous control, it was expected that they will show high levels of cue-utilisation in the Mostly Predictive block relative to the Baseline block. For untransformed data for the Cued Visual Search task, see Tables 6.3 and 6.4. To measure cue-utilisation in the Cued Visual Search task, cueing ratios were calculated for singleton-absent trials (Response Times: invalid / valid median response time; Accuracy: valid / invalid mean accuracy) whereby a cueing ratio above 1 suggests high levels of cue-utilisation. Separate Block (2 levels: Mostly Predictive, Baseline) x Age-Group (2 levels: young, older adults) mixed ANOVAs were conducted on average cueing ratios for response times and accuracy data.

Table 6.3. Untransformed average median response times, standard error and 99% confidence intervals across block, cue validity and singleton-presence for two age-groups.

			Young Adults			*Older Adults*		
			M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Mostly Predictive block	*Valid*	*Absent*	.66	.02	.62, .71	.95	.02	.87, 1.03
		Present	.69	.02	.64, .74	1.00	.03	.92, 1.09
	Invalid	*Absent*	.87	.03	.78, .96	1.22	.04	1.12, 1.32
		Present	.89	.03	.81, .97	1.25	.04	1.15, 1.35
Baseline block	*Valid*	*Absent*	.72	.02	.66, .78	1.03	.03	.95, 1.10
		Present	.74	.02	.68, .79	1.06	.03	.98, 1.14
	Invalid	*Absent*	.70	.02	.64, .76	.99	.03	.91, 1.06
		Present	.76	.02	.70, .82	1.08	.03	1.00, 1.17

Note: M – mean; SE – standard error; 99% CI – 99% confidence intervals [lower, upper bound].

Table 6.4. Untransformed average accuracy, standard error and 99% confidence intervals across block, cue validity and singleton-presence for two age-groups.

			Young Adults			*Older Adults*		
			M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Mostly Predictive block	*Valid*	*Absent*	.98	.003	.97, .99	.99	.002	.98, .99
		Present	.98	.01	.96, .99	.98	.003	.98, .99
	Invalid	*Absent*	.95	.01	.94, .97	.98	.01	.96, .99
		Present	.97	.01	.95, .98	.98	.004	.97, 1.00
Baseline block	*Valid*	*Absent*	.97	.004	.96, .98	.98	.003	.98, .99
		Present	.97	.01	.95, .98	.98	.005	.97, 1.00
	Invalid	*Absent*	.98	.01	.97, 1.00	.99	.004	.98, 1.00
		Present	.97	.01	.95, .99	.98	.004	.97, .99

Note: M – mean; SE – standard error; 99% CI – 99% confidence intervals [lower, upper bound].

Response Time

A non-significant Block x Age-Group interaction was found ($F(1,81) = .002$, $p = .966$, $\eta^2_p < .001$; *see Figure 6.3*). The main effect of Age-Group was not significant ($F(1,81) = .36$, $p = .550$, $\eta^2_p = .004$; Young Adults: M = 1.15, SE = .02 [99% CI 1.11, 1.19]; Older Adults: M = 1.13, SE = .02 [99% CI 1.09, 1.18]). A significant Block main effect was found ($F(1,81) = 241.34$, $p < .001$, $\eta^2_p = .75$). This shows that all participants had larger cueing ratios in the Mostly Predictive block compared to the Baseline block.

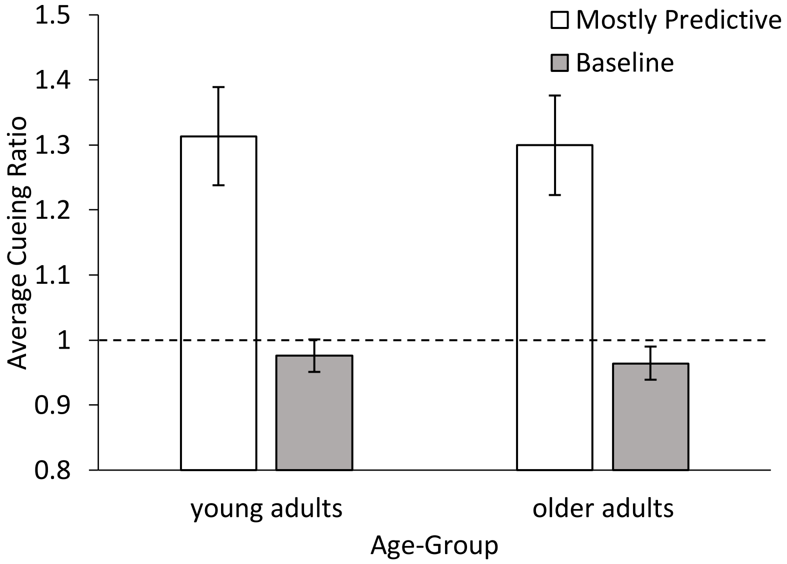

Figure 6.3. Average Cueing Ratios in the Mostly Predictive block (white bars) and the Baseline block (grey bars) across two age-groups. Cueing ratios above 1, suggest cue-utilisation. Error bars represent 99% confidence intervals.

Accuracy

The findings from the assessment of accuracy, replicate the results seen in response time above. The Block x Age-Group interaction was non-significant ($F(1,81) = 3.56$, $p = .063$, $\eta^2_p = .04$; *see Table 6.5*). The Age-Group main effect was also not significant ($F(1,81) = .03$, $p = .855$, $\eta^2_p < .001$; Young Adults: M = 1.01, SE = .01 [99% CI .99, 1.02]; Older Adults: M = 1.00, SE = .01

[99% CI .99, 1.02]). The Block main effect was found to be significant (*F*(1,81) = 28.05, $p < .001$, $\eta^2_p = .26$). Cueing ratios in the Mostly Predictive block were larger than in the Baseline block.

Table 6.5. Average Cueing Ratios in accuracy, Standard Error and 99% Confidence Intervals for both Block conditions and Age-Groups.

	Young Adults			*Older Adults*		
	M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Baseline	.99	.01	.97, 1.00	1.00	.01	.98, 1.01
Mostly Predictive	1.02	.01	1.01, 1.04	1.01	.01	1.00, 1.03

Note: M = Mean; SE = Standard Error; 99% CI = 99% Confidence Intervals [lower, upper bound].

AX-CPT

Endogenous control in the AX-CPT is defined by early maintenance of cue information (i.e. “A” or “B” information). I aimed to assess cue-utilisation in the AX-CPT by first considering the differences in performance between the four trial types (AX, BX, AY & BY) in Young and Older Adults. Cue-utilisation is expected to lead to worse performance on AY trials relative to all other trial types, particularly BX trials (Braver et al., 2005, 2009; Paxton et al., 2008).

I then used a measure of cue-utilisation which controls for age-related slowing in performance and is similar to my measure of cueing ratios in the Cued Visual Search task. Past research has commonly defined AY trials as an invalid trial type, as the “A” cue encourages participants to anticipate an “X” probe and prepare to make a positive response (Chatham et al., 2009; Redick, 2014). In contrast BX trials are classed as a valid trial type, as early processing of the “B” cue signals users to prepare to make a negative response. Of the several measures commonly used in the AX-CPT, the Proactive Behavioural Index (PBI) was chosen to compare the difference in behavioural responses on AY (invalid trials) and BX trials (valid trials; see Braver et al., 2007; Gonthier et al., 2019). PBI was calculated for median response times only ((AY – BX) / (AY + BX)). A positive score above 0, suggests high levels of cue-utilisation (or proactive control), whereas a negative score below 0, suggests low levels of cue-utilisation (or reactive control). It is expected that those who have developed endogenous control will have slower response times on AY trials relative to BX trials, suggestive of positive PBI scores.

Response Time

Performance in the AX-CPT was assessed by conducting a Trial-Type (4 levels: AX, BX, AY, BY) x Age-Group (2 levels: Young, Older Adults) mixed ANOVA on median response times (s).

The Trial-Type x Age-Group interaction was not significant ($F(2.36, 190.95) = 3.45$, $p = .027$, $\eta^2_p = .04$; *see Figure 6.4*). The main effect of Trial-Type was significant ($F(2.36, 190.95) = 342.32$, $p < .001$, $\eta^2_p = .81$). This showed that participants were significantly slower on AY trials relative to all other trial types (all *ps* < .001). Participants were faster on BX trials relative to AX trials ($p < .001$), but there was no difference in response times between BX and BY trials ($p = 1.00$). Response times on AX trials were slower than BY trials ($p < .001$). A main effect of Age-Group was also found ($F(1, 81) = 58.94$, $p < .001$, $\eta^2_p = .42$), which shows that overall Older Adults were slower at responding than Young Adults.

According to the pre-registration for the intended study, I had planned to run a one-way ANOVA on average PBI scores with 5 levels for each age-group and follow-up this analysis with a quadratic trend analysis to assess whether PBI scores declined with increasing age. As the current study includes data for two age-groups, an independent samples t-test was conducted to compare Young and Older Adults' average response time PBI scores. A significant difference was found in PBI scores between Young and Older Adults ($t(81) = 4.97$, $p < .001$, two-tailed [99% CI_{Mdiff} .05, .15], Cohen's $d = 1.09$ [99% CI .48, 1.70], Hedges' $g = 1.08$ [99% CI .48, 1.68][28]; *see Figure 6.5*

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[28] Cohen's $d_s = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{(n_1-1)SD_1^2+(n_2-1)SD_2^2}{n_1+n_2-2}}}$ was used to calculate the difference between independent sample means, which was divided by the pooled sample standard deviation. This is a common measure of effect size for between-subject comparisons (Lakens, 2013).

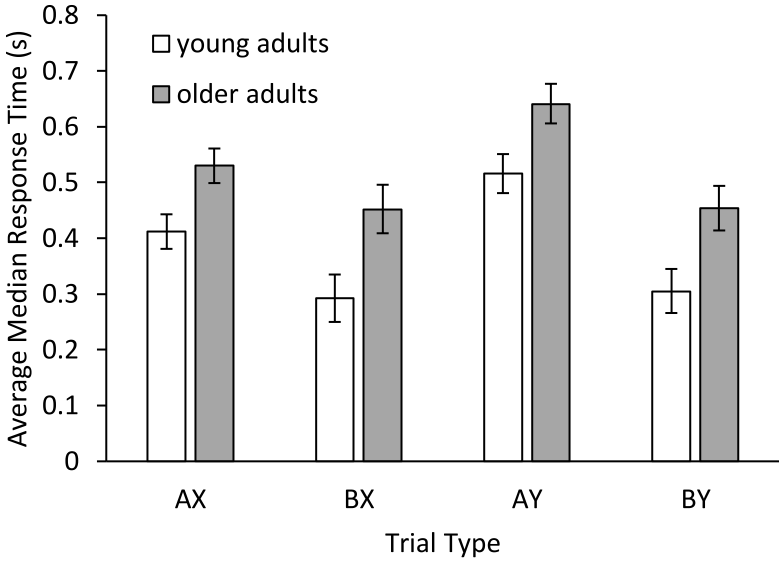

Figure 6.4. Average Median Response Times (s) across AX, Bx, AY and BY trial types in Young Adults (white bars) and Older Adults (grey bars). Error bars represent 99% confidence intervals.

overleaf). The significant difference found between Young and Older Adults' PBI scores, showed that Young Adults had significantly larger PBI scores than Older Adults. As PBI scores for both age-groups were positive, a signal for endogenous (or proactive) control use, I explored whether PBI scores for each age-group were significantly greater than 0 using Bonferroni corrected one-sample t-tests. PBI scores for both Young Adults and Older Adults were significantly greater than 0 (Young Adults: $t(41) = 23.80$, $p < .001$, two-tailed [99% CI_{Mdiff} .25, .31], Cohen's d[29] = 3.67 [99% CI 2.57, 4.80], Hedges' $g = 3.60$ [99% CI 2.53, 4.71]); Older Adults: $t(40) = 12.07$, $p < .001$, two-tailed [99% CI_{Mdiff} .14, .23], Cohen's $d = 1.89$ [99% CI 1.21, 2.56], Hedges' $g = 1.85$ [99% CI 1.91, 2.51]).

Accuracy

Mean accuracy across all four trial types was relatively high (*see Table 6.6*). In particular, both Young and Older Adults had perfect accuracy on BY trials. From the standard deviation and confidence intervals, there was

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[29] Cohen's $d_z = \frac{t}{\sqrt{N}}$ was used; a common measure of effect size for one-sample t-tests (Lakens, 2013).

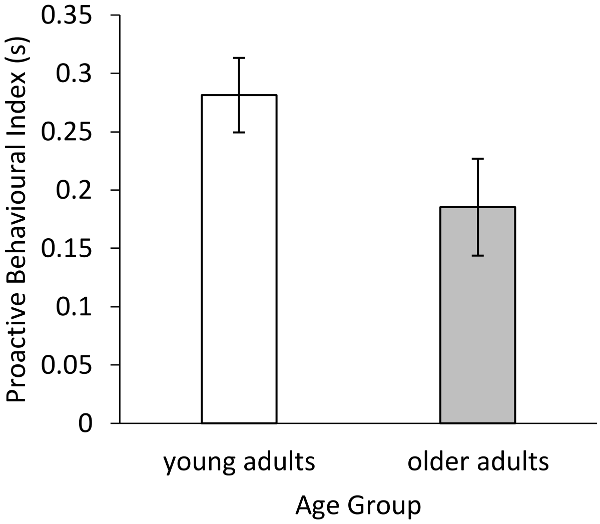

Figure 6.5. Average Proactive Behavioural Index (PBI; s) for Young Adults (white bars) and Older Adults (grey bars). PBI scores above 0, suggest cue-utilisation. Error bars represent 99% confidence intervals.

little variability in accuracy within each trial type for both age-groups, particularly BY trials where there was no variability in accuracy. No further analysis was conducted on accuracy data.

Table 6.6. Mean accuracy, Standard Deviation, Standard Error and 99% Confidence Intervals across all Trial Types and Age-Groups.

	Young Adults				*Older Adults*			
	M	*SD*	*SE*	*99% CI*	*M*	*SD*	*SE*	*99% CI*
AX	.99	.02	.003	.98, 1.00	.99	.02	.003	.98, .99
BX	.99	.03	.01	.97, 1.00	.99	.04	.01	.97, 1.00
AY	.92	.09	.01	.89, .95	.96	.05	.01	.93, .99
BY	1.00	.00	.00	1.00, 1.00	1.00	.00	.00	1.00, 1.00

Note: M = Mean; SD = Standard Deviation; SE = Standard Error; 99% CI = 99% Confidence Intervals [lower, upper bound].

Overall, the analyses for Aim 1 showed that Older Adults utilised cues in the Mostly Predictive block of the Cued Visual Search task as effectively as

Young Adults. In addition, Older Adults were able to utilise the cues in the AX-CPT but not as robustly as Young Adults (reduced PBI scores).

Aim 2: *Cue-Utilisation: Relationship Between Cued Visual Search and AX-CPT*

For this aim, I investigated the predictive relationship in cue-utilisation between the Cued Visual Search task and the AX-CPT. Specifically, I was interested in whether a significant proportion of the variance in the amount of cue-use experienced in the Mostly Predictive block (on singleton-absent trials), could be explained by cue-use in the AX-CPT. I also assessed whether the age-difference between young and older adulthood, played a moderating effect on this relationship. To assess this aim a moderation analysis, consistent with the approach used in Chapter 3, was conducted. I will first describe the variables included in this analysis, followed by the results.

Measure of Colour Categorisation

Individual differences in colour categorisation was included in this analysis as a control measure, to examine whether it would explain a significant proportion of the variance in cue-utilisation in the Mostly Predictive block. A linear regression function was fitted to averaged data for each block condition to understand the level of slope with increments from one categorical colour to another (R^2 to assess fit of the data ranged from .50 - .99 across all participants). A composite slope score was produced for each participant by averaging their slopes across all six colour block conditions. High composite slope scores suggests high discriminability between colours. As a secondary question for the current moderation analysis, it was expected that those with poorer colour discriminability would have smaller cueing ratios in the Mostly Predictive block of the Cued Visual Search task.

Measures of Cue-Utilisation

For the measure of cue-utilisation in the Cued Visual Search task, response time cueing ratios on singleton-absent trials in the Mostly Predictive block (invalid / valid median response time) were used. Cueing ratios above 1 suggest high levels of cue-utilisation. The measure of cue-utilisation chosen in the AX-CPT was response time PBI scores ((AY – BX) / (AY + BX)). PBI scores above 0 signify high levels of cue-utilisation in this task. As highlighted previously, PBI scores inform us about the amount of cue-use in the AX-CPT by considering the difference in performance on invalid (AY) and valid (BX) trials, which suggests that it is an effective counterpart to cueing ratios in the Cued Visual Search task.

Measure of Age-Related Moderation

To understand whether the predictive relationship between Cued Visual Search and AX-CPT cue-utilisation is moderated by age-related increases from young to older adulthood, an interaction term (moderator predictor variable) was created. A dummy variable was produced by assigning weights to each age-group. Young Adults were assigned a weight of “0” to act as the null or baseline measure for the model, whereas Older Adults were assigned a weight of “1”. The interaction term was computed by multiplying each participant’s AX-CPT PBI score by the dummy variable. This resulted in one interaction term to make an age-group comparison: PBI x Young vs Older Adults. The method of coding described above was used, as the key question for this analysis was to understand if older adulthood plays a moderating role in changing the relationship between the Cued Visual Search task and the AX-CPT in the amount of cue-use experienced. If Older Adults utilise endogenous control differently in a spatial relative to a non-spatial task, the predictive relationship between Cued Visual Search and AX-CPT cue-use may differ in older adulthood relative to young adulthood.

Hierarchical Multiple Regression

A hierarchical multiple regression analysis was conducted whereby cueing ratios (on singleton-absent trials) in the Mostly Predictive block of the Cued Visual Search task was defined as the outcome variable and predictor variables were inputted into two models. Model 1 consisted of: PBI score in the AX-CPT, Young vs Older Adult Dummy Variable and Composite Slope Score. Model 2 inputted one additional predictor variable: PBI x Young vs Older Adults.[30]

The analysis showed that Model 1 explained .90% (Adjusted R^2 = -2.8%) of the variance in cueing ratios but this was non-significant ($F(3, 79) = .25$, $p = .86$; *see Table 6.7*). The addition of the interaction term led Model 2 to explain 1.7% (Adjusted R^2 = -3.4%) of the variance in cueing ratios, which did not meet significance ($F(4, 78) = .33$, $p = .855$). Model 2 explained an additional 1.1% of the variance in cueing ratios, relative to Model 1 but this change in variance explained was not found to be significant ($F(1, 78) = .58$, $p = .449$).

Table 6.7. Standardised Beta Coefficients for predictors of cueing ratios in the Mostly Predictive block.

	Model 1 *$R^2 = .009$*	*Model 2* *$R^2 = .017$* *$\Delta R^2 = .007$*
Predictor	*β*	*β*
PBI Score	.06	-.064
Composite Slope Score	-.073	-.069
Young vs Older Adults	.011	-.258
PBI x Young vs Older Adults		.233

Note: * $p < .05$; ** $p < .01$; *** $p < .001$.

As both Model 1 and Model 2 were non-significant, no further follow-up analysis was required. For exploratory purposes, Pearsons' Correlation Coefficients were computed between AX-CPT PBI scores and cueing ratios (on singleton-absent trials) in the Mostly Predictive block for each age-group (*see Figure 6.6A*). In Young Adults, a non-significant negative relationship was

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[30] Pre-registration for the assessment of lifespan changes showed a total of nine predictor variables were planned to be included in Model 2 (*see Appendix 6.1*). Age and two interaction terms and two dummy variables for young child vs older child and older child vs adult age-group comparisons were not included in the current analysis.

found between PBI scores and cueing ratios in the Mostly Predictive block (*r*(42) = -.05, *p* = .735). In Older Adults, a non-significant positive correlation was found between PBI scores and cueing ratios (*r*(41) = .13, *p* = .41). The unstandardised predicted values from Model 2 corroborate these findings and show poor fit of the data (*see Figure 6.6B*).

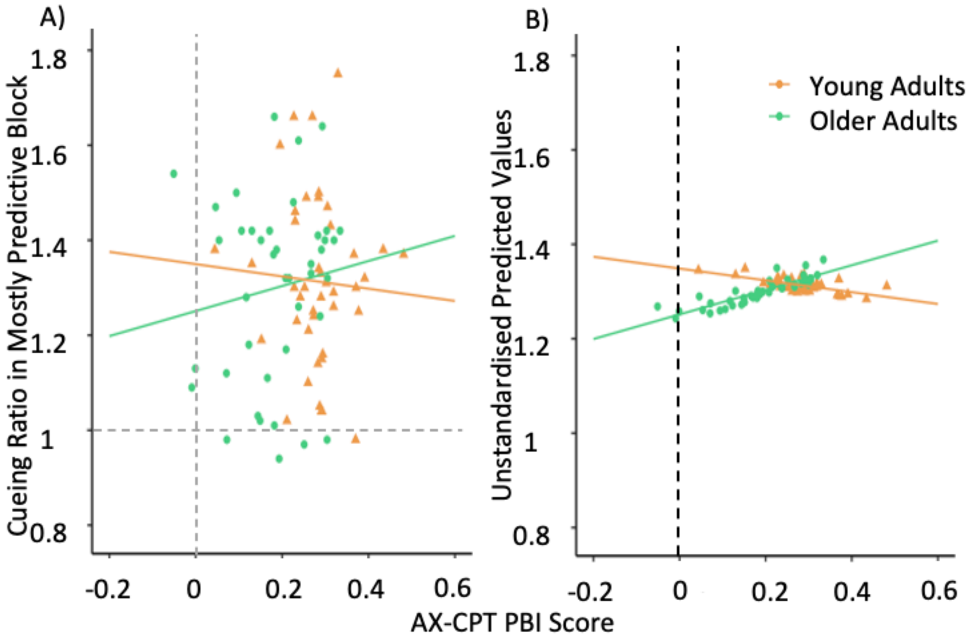

Figure 6.6. The relationship between cue-utilisation in the Cued Visual Search task and the AX-CPT for two age-groups: Young Adults (orange) and Older Adults (green). This relationship is depicted by A) Pearsons' Correlation Coefficients: cueing ratios on singleton-absent trials in the Mostly Predictive block and Proactive Behavioural Index (PBI) scores in the AX-CPT (Young Adults: *r* = -.05; Older Adults: *r* = .13). B) Multiple Regression: unstandardised predicted values from Model 2 and PBI scores as described above. Linear regression lines are fitted to the data.

Aim 3: *Attentional Capture*

This analysis is concerned with Aim 3 for the Cued Visual Search task, to assess whether cues in the Mostly Predictive block, relative to the Baseline block, influenced levels of distraction produced by the singleton distracter. To measure the amount of distraction experienced, distraction ratios were calculated (Response Time: singleton-present / singleton-absent median response time; Accuracy: singleton-absent / singleton-present mean accuracy). Distraction ratios above 1, suggest high levels of distraction by the singleton distracter. Separate Block (2 levels: Mostly Predictive, Baseline) x Cue Validity (valid, invalid) x Age-Group mixed ANOVAs were conducted on average distraction ratios for both response time and accuracy.

This replicates the analysis that I used to assess the same aim in Chapter 3 with the exception of no Low Predictive block in the current chapter. To ensure consistency, I assigned “valid” and “invalid” variables to trials in the Baseline block using the same procedure as in Chapters 3 and 5. This variable assignment matched the Mostly Predictive block such that 66.67% of trials in the Baseline block were assigned “valid” and the remaining 33.33% of trials in this block were assigned “invalid” for each participant. For instance, a valid trial in the Mostly Predictive block shared the same search-display as the assigned “valid” trial in the Baseline block, but only differed in terms of the cue-display. I will refer to the assigned trials in the Baseline block as “valid” and “invalid” in quotation.

Response Time

The Block x Cue Validity x Age-Group interaction was not significant ($F(1,81) = .61$, $p = .438$, $\eta^2_p = .01$). The Block x Cue Validity interaction was significant ($F(1,81) = 30.35$, $p < .001$, $\eta^2_p = .27$; *see Figure 6.7*). This showed that there were no differences in distraction ratios between valid and invalid trials in the Mostly Predictive block ($p = .083$). However, distraction ratios on assigned “valid” trials in the Baseline block were significantly smaller than assigned “invalid” trials in the same block condition ($p < .001$). Comparisons between block conditions showed that participants had smaller distraction ratios on invalid trials in the Mostly Predictive block relative to assigned “invalid” trials in the Baseline block ($p < .001$). Distraction ratios on valid trials did not significantly differ between block conditions ($p = .022$). The main effects of Block ($F(1,81) = 4.95$, $p = .029$, $\eta^2_p = .06$; Mostly Predictive: M = 1.04, SE = .01 [99% CI 1.03, 1.06]; Baseline: M = 1.06, SE = .01 [99% CI 1.04, 1.08]) and Cue Validity (*F*(1,81) = 5.43, *p* = .022, η^2_p = .06; Valid: M = 1.04, SE = .01 [99% CI 1.03, 1.06]; Invalid: M = 1.06, SE = .01 [99% CI 1.04, 1.08]) did not reach significance. The main effect of Age-Group and all other interactions were non-significant.

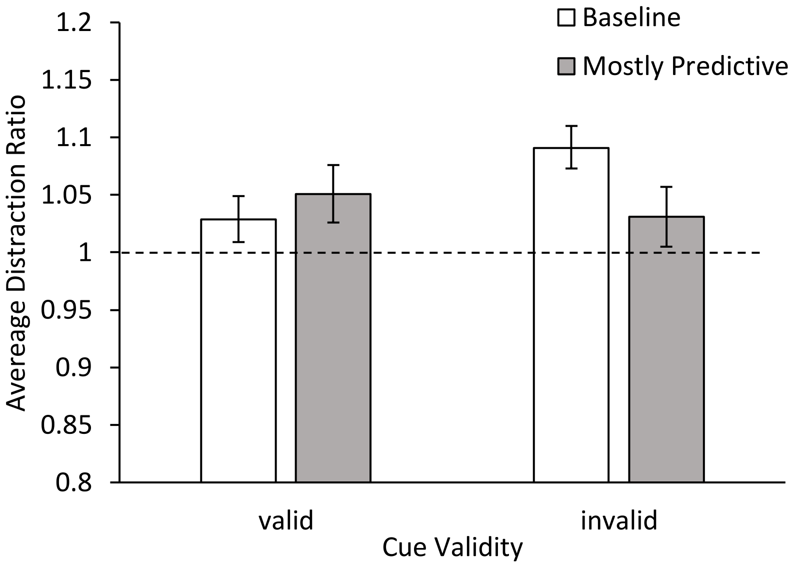

Figure 6.7. Average Distraction Ratios for valid and invalid trials in the Baseline (white bars) and Mostly Predictive (grey bars) blocks. Distraction Ratios above 1, suggest attentional capture. Error bars represent 99% confidence intervals.

Accuracy

The Block x Cue Validity x Age-Group interaction failed to meet significance (*F*(1,81) = .03, *p* = .856, $\eta^2_p < .001$; *see Table 6.8*). The Block x Cue Validity interaction was not significant (*F*(1,81) = 3.43, *p* = .068, η^2_p = .04). The main effects of Block (*F*(1,81) = 5.24, *p* = .025, η^2_p = .06; Mostly Predictive: M = 1.00, SE = .003 [99% CI .99, 1.01]; Baseline: M = 1.01, SE = .003 [99% CI 1.00, 1.01]) and Cue Validity (*F*(1,81) = .29, *p* = .589, η^2_p = .004; Valid: M = 1.00, SE = .003 [99% CI .99, 1.01]; Invalid: M = 1.00, SE = .004 [99% CI .99, 1.01]) were both non-significant. The Age-Group main effect and all other interactions with this factor were non-significant.

Table 6.8. Average distraction ratio (Standard Error [99% Confidence Intervals]) for accuracy data across block and cue validity for both age-groups.

		Young Adults	*Older Adults*
Mostly Predictive block	*Valid*	1.00 (.01 [.99, 1.02])	1.00 (.01 [.99, 1.02])
	Invalid	.99 (.01 [.97, 1.01])	.99 (.01 [.97, 1.01])
Baseline block	*Valid*	1.01 (.01 [.99, 1.02])	1.00 (.01 [.99, 1.02])
	Invalid	1.01 (.01 [.99, 1.03])	1.01 (.01 [.99, 1.02])

Exploratory Analyses

The findings from the analysis above yielded questionable results in the Baseline block. I will further reflect and provide an in-depth discussion of this result in Chapter 8: General Discussion (*see page 256*). To further explore Aim 3 in the current chapter, I conducted additional forms of analyses. Both analyses removed the assignment of “valid” and “invalid” variables from the Baseline block and calculated distraction ratios across all neutral trials in this condition. I will describe the purpose of each analysis before reporting the findings.

First, I investigated whether participants in each age-group experienced attentional capture from the singleton distracter. This was assessed by conducting Bonferroni corrected one-sample t-tests on average distraction ratios in the Baseline block (consisting of only neutral trials). Distraction ratios which are significantly larger than 1, suggest participants experienced attentional capture by the singleton distracter.

Second, separate Cue Validity (3 levels: valid, invalid, neutral) x Age-Group mixed ANOVAs on average distraction ratios were conducted for both response times and accuracy. The Cue Validity factor used in this analysis consisted of data from the Mostly Predictive block (valid and invalid trials) as well as data from the Baseline block (neutral trials).

Third, I assessed whether maintenance and inhibition abilities in the Cued Visual Search task are related to one another and whether this changes with age. This question is an overarching theme in this thesis and was assessed in Chapter 3 which showed no predictive relationship between these two skills in young adults. It is known that general maintenance and inhibition abilities diminish in seniority (Clapp & Gazzeley, 2012; Lustig et al., 2007), but it is uncertain how the dynamic between these skills in the Cued Visual Search task changes with age. I aim to explore this result by investigating whether it is replicated in the current dataset and whether this relationship remains constant throughout adulthood.

Finally, I consider the relationship between colour discrimination and distraction ratios in the Baseline block to further understand the abnormalities in this condition. In Chapter 3 participants experienced less distraction on valid vs invalid trials, which may have been driven by differences in the assigned trials in the Baseline block. Chapter 4 showed cross-colour priming did not explain these differences between assigned trials in this condition. In the current chapter, I will further explore whether colour discrimination is associated with distraction in the Baseline block using Pearsons' Correlation Coefficients for each age-group.

Attentional Capture - Exploratory

Response Time

The one-sample t-tests showed that average distraction ratios in the Baseline block for both Young Adults ($t(41) = 5.31$, $p < .001$, two-tailed [99% CI_{Mdiff} .02, .07], Cohen's $d^{31} = .82$ [99% CI .36, 1.28], Hedges' $g = .80$ [99% CI .35, 1.25]) and Older Adults ($t(40) = 6.28$, $p < .001$, two-tailed [99% CI_{Mdiff} .03, .07], Cohen's $d = .98$ [99% CI .49, 1.47], Hedges' $g = .96$ [99% CI .48, 1.44]) were significantly greater than 1.

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[31] Cohen's $d_z = \frac{t}{\sqrt{N}}$ was used to calculate the mean difference from the test statistic 1; a common measure of effect size for one-sample t-test comparisons (Lakens, 2013).

The findings for whether cue-utilisation influenced attentional capture by the singleton distracter, showed that the Cue Validity x Age-Group interaction was non-significant (*F*(2,162) = .12, *p* = .889, η^2_p = .001; *see Figure 6.8*). The main effects of Cue Validity (*F*(2,162) = 2.27, *p* = .107, η^2_p = .03) and Age-Group (*F*(1,81) = .19, *p* = .664, η^2_p = .002) were also not significant.

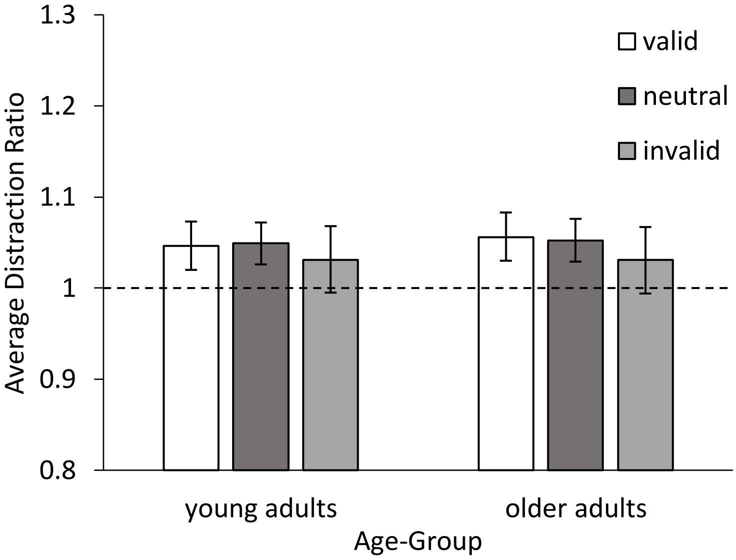

Figure 6.8. Average Distraction Ratios for valid (white bars), neutral (dark grey bars) and invalid (light grey bars) trials in the Mostly Predictive and Baseline blocks. Distraction Ratios above 1, suggest attentional capture. Error bars represent 99% confidence intervals.

Accuracy

The one-sample t-tests on average distraction ratios in the Baseline block were not found to significantly differ from 1 for both age-groups (Young Adults: *t*(41) = .62, *p* = .539, two-tailed [99% CI$_{Mdiff}$ -.01, .02], Cohen's *d* = .10 [99% CI -.30, .49], Hedges' *g* = .09 [99% CI -.30, .48]; Older Adults: *t*(40) = .66, *p* = .514, two-tailed [99% CI$_{Mdiff}$ -.01, .01], Cohen's *d* = .10 [99% CI -.30, .51], Hedges' *g* = .10 [99% CI -.30, .50]). The Cue Validity x Age-Group interaction was not significant (*F*(2,162) = .09, *p* = .911, η^2_p = .001; *see Table 6.9*). The main effects of Cue Validity (*F*(2,162) = 2.35, *p* = .099, η^2_p = .03) and Age-Group (*F*(1,81) = .27, *p* = .608, η^2_p = .003) did not meet significance.

Altogether, the findings show that endogenous cue-utilisation on valid trials in the Mostly Predictive block did not reduce attentional capture in Young and Older Adults. Contrary to predictions, the results could suggest that attentional capture is reduced on invalid trials when the search-displays between the Mostly Predictive and the Baseline blocks are matched; yielding a stronger baseline comparison. The findings will be further discussed.

Table 6.9. Average distraction ratio (Standard Error [99% Confidence Intervals]) for accuracy data across valid, invalid (in Mostly Predictive block) and neutral (in Baseline block) trials for both age-groups.

		Young Adults	*Older Adults*
Mostly Predictive block	*Valid*	1.00 (.01 [.99, 1.02])	1.00 (.01 [.99, 1.02])
	Invalid	.99 (.01 [.97, 1.01])	.99 (.01 [.97, 1.01])
Baseline block	*Neutral*	1.00 (.004 [.99, 1.01])	1.00 (.004 [.99, 1.01])

Maintenance & Inhibition Relationship

To further assess Aim 3, the relationship between maintenance and inhibition skills, measured independently, was explored using the same analysis as Chapter 3. It is predicted that better maintenance of the cue would lead to reduced distraction from the singleton distracter. For my measure of maintenance, cueing ratios on singleton-absent trials in the Mostly Predictive block was used. The measure of inhibition was distraction ratios in the Baseline block. A multiple linear regression was used which included an interaction term to assess if age moderates the predictive relationship between these two skills.

The outcome variable was distraction ratios in the Baseline block. Model 1 consisted of two predictor variables: 1) cueing ratios in the Mostly Predictive block and 2) dummy variable Young vs Older Adult Age-Group.

Model 2 inputted the moderator predictor variable Cueing x Young vs Older Adults.

The findings showed that Model 1 did not explain a significant proportion of the variance in distraction ratios in the Baseline block (R^2 = .60%, Adjusted R^2 = -1.90%, *F*(2, 80) = .24, *p* = .789). The addition of the moderator predictor variable in Model 2 did not significantly explain an additional proportion of the variance in the outcome variable (R^2 = .90%, Adjusted R^2 = -2.90%, *F*(3, 79) = .24, *p* = .867; *see Table 6.10*) nor did it differ from Model 1 (R^2 change = .30%, *F*(1, 79) = .26, *p* = .615).

Pearsons' Correlation Coefficients between cueing ratios on singleton-absent trials in the Mostly Predictive block and distraction ratios in the Baseline block, show a weak negative relationship in Young Adults (*r*(42) = -.12, *p* = .454) and Older Adults (*r*(41) = -.02, *p* = .908; *see Figure 6.9*). This suggests that better maintenance of the cue was weakly related to poorer distraction of the singleton distracter, when both skills were measured independently.

Table 6.10. Standardised Beta Coefficients for predictors of distraction ratios in the Baseline block.

	Model 1 $R^2 = .006$	*Model 2* $R^2 = .009$ $\Delta R^2 = .003$
Predictor	β	β
Cueing Ratio Score	-.07	-.13
Young vs Older Adults	.03	-.37
Cueing x Young vs Older Adults		.41

Note: * $p < .05$; ** $p < .01$; *** $p < .001$.

The results from this analysis suggest that the measures of maintenance and inhibition skills are not related to one another (replicating the result from Chapter 3) and this pattern of results does not change in older adulthood.

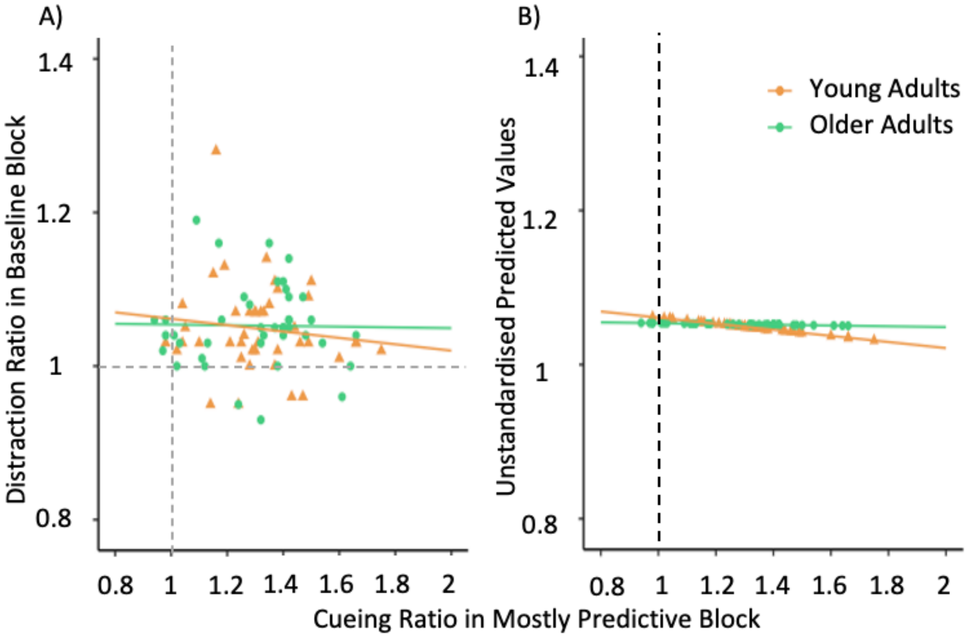

Figure 6.9. The relationship between maintenance and inhibition abilities in the Cued Visual Search task for two age-groups: Young Adults (orange) and Older Adults (green). This relationship is depicted by A) Pearsons' Correlation Coefficients: cueing ratios on singleton-absent trials in the Mostly Predictive block and distraction ratios in the Baseline block (inhibition; Young Adults: *r* = -.12; Older Adults: *r* = -.02). B) Multiple Regression: unstandardised predicted values from Model 2 and cueing ratios as described above. Linear regression lines are fitted to the data.

Colour Discrimination & Baseline Block

I considered the relationship between colour discrimination ability and the amount of distraction experienced in the Baseline block to understand the abnormalities in this condition. Pearsons' Correlation Coefficients were calculated for each age-group between composite colour slopes and distraction ratios in the Baseline block (*see Appendix 6.3 for descriptive statistics*). It was expected that poorer discriminability between different categorical colours may lead to less distraction in the Baseline block.

The relationship between these measures showed weak negative correlations in Young (*r*(42) = -.05, *p* = .772) and Older Adults (*r*(41) = -.01, *p* = .966; *see Figure 6.10*). Suggesting that poorer colour discriminability was weakly related to more distraction in the Baseline block. Individual differences in colour categorisation was weakly related to distractibility in the Baseline block.

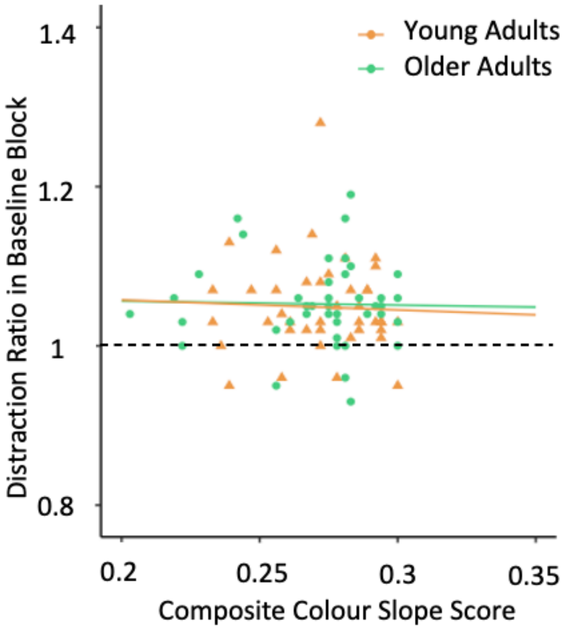

Figure 6.10. The relationship between composite colour slope scores (maximum score = .30) and distraction ratios in the Baseline block for two age-groups: Young Adults (orange; *r* = -.05) and Older Adults (green; *r* = -.01). Linear regression lines are fitted to the data.

Discussion

This study aimed to understand age-related changes in endogenous cue-utilisation during adulthood using two experimental paradigms. Specifically, I assessed the predictive relationship between cue-utilisation in the Cued Visual Search task and the AX-CPT. The findings showed that in Cued Visual Search, there were no age-related differences in the ability to maintain early cue information for guiding attention towards an upcoming target. Interestingly in the AX-CPT, both young and older adults used an endogenous strategy to anticipate and expect the probe but this form of control, was used more robustly in young relative to older adults. The lack of predictive relationship in cue-maintenance found between the two measures of endogenous control, suggest that this higher-order process is domain-specific and may be dependent on the demands of the task. With regard to the aims investigating attentional capture, the findings show that both young and older adults may have experienced reduced levels of distraction on invalid trials, when provided with an endogenous cue to guide attention. I will discuss each of the findings in turn.

Cue-Utilisation

Cued Visual Search

The ability to maintain a cue to orient attention towards the featural location of the target is shown to be age-invariant during adulthood. In Cued Visual Search, cue-utilisation is defined by faster response times on valid, relative to invalid trials in the Mostly Predictive block; a condition which encourages early maintenance of cue information by manipulating the predictive context of the cue. The findings showed that both young and older adults had significantly larger cueing ratios (invalid / valid median response times) in the Mostly Predictive block, compared to the Baseline block. It should be noted that cueing ratios in the Baseline block were below 1 in both age-groups, which could be indicative of variability between assigned trials in this condition (i.e. faster on "invalid" vs "valid" trials). For further discussion on this finding, see Chapter 8 | General Discussion (page 256). Nevertheless, the lack of an interaction found with Block and Age-Group suggests that cue-utilisation in Cued Visual Search does not change with increasing age. This supports previous research which have also shown age-equivalence effects between young and older adults, for the use of cue-utilisation when searching for a featural target (Humphrey & Kramer, 1997; Iarocci et al., 2009; Greenwood & Parasuraman, 2004; Madden et al., 2004; Madden & Plude, 1993). It is largely assumed that search for a single-featural target is retained in older adulthood as this age-group rely on utilising an exogenous process to guide attention towards a "pop out" target (Müller-Ohering et al., 2013). However, the findings in the current chapter demonstrate that older adults are able to utilise early endogenous cues rather than rely on exogenously responding to the featural tilted line target.

The main results further our current understanding of endogenous control, as older adults were encouraged to maintain a central featural cue, by learning about its predictability for locating the target; a skill which has been implicated in the use of visual working memory and long term memory to sustain the activation of the learned association (Carlisle et al., 2011; Hahn & Buttaccio, 2018; Woodman, Carlisle & Reinhart, 2013). This may be due to the reduced level of translation associated with interpreting the cue, as more abstract cues have shown reduced levels of learned associations in older adults which implicated the levels of cue-utilisation in this age-group (Hahn & Buttaccio, 2018). Suggesting, cue translation may play an important role in the guidance of visual attention in aging populations.

Moreover, the age-invariance in cue-utilisation suggests that the functionality of the fronto-parietal network associated with endogenous control is preserved in seniority but could be a consequence of a compensatory mechanism. Specifically, the posterior parietal cortex has commonly been associated with activations in the volitional control of visuo-spatial attention (for a review, see Shomstein & Gottleib, 2016). Research has shown that activity in the superior frontal and inferior parietal cortices are associated with the volitional guidance of attention from an early cue (Corbetta & Schulman, 2002). In older adulthood, activity in the prefrontal and posterior parietal areas are commonly found to be increased and bilateral relative to the reduced unilateral activity found in the same regions in young adults (Cabeza, 2002; Corbetta & Schulman, 2002; Huang et al., 2012). This pattern of results is considered to be a compensatory mechanism specific to older adults, to offset the effects of age-related neural degradation (Huang et al., 2012). As such, the age-invariance effects found in cue-utilisation at the behavioural level, may be resultant of compensatory mechanisms demonstrated at the neural level.

AX-CPT

The results from the AX-CPT show that endogenous control is preserved in older adulthood, but it is less robust to the form of control acquired by young adults. Cue-utilisation was measured in this task by comparing performance on AY trials (invalid) and BX trials (valid), whereby larger Proactive Behavioural Index (PBI) scores are reflective of slower response times on AY relative to BX trials (Braver et al., 2007). Interestingly, the results showed that both young and older adults had PBI scores that were significantly greater than 0. This suggests that endogenous (proactive) control, as characterised by the AX-CPT, is preserved in older adulthood which opposes past research that showed this skill to deteriorate into exogenous (reactive) form of control (Braver et al., 2007, 2009; Paxton et al., 2008).

The findings also show an age-related change in this task, as the average PBI score for older adults was significantly smaller than that found for young adults. It is possible that older adults are able to maintain early cue information but less robustly, as shown by the smaller difference found between AY and BX trial response times. Many suggest that older adults have a *goal-maintenance deficit* due to impairments in prefrontal regions, whereby their ability to maintain information concerning the context of events (i.e. probe “X” usually follows cue “A”) decays at a faster rate resulting in an exogenous form of control (Braver et al., 2001, 2005). However, others propose that learned anticipation following the cue does not differ, but conflict monitoring signals to suppress the tendency to make a target response on derivative trials is compromised in older adults (Hämmerer et al., 2010). Contrary to the former perspective, the current study showed the ability to maintain contextual information to build an expectation from the cue is retained in older adulthood. Therefore, the smaller difference found between AY and BX trials in older adults, reflected by PBI scores, may be suggestive of a dampened ability to monitor conflict on derivative trials relative to young counterparts.

Relationship in Cue-Utilisation Between Cued Visual Search & AX-CPT

Despite evidence suggesting the use of endogenous cue-utilisation in both the Cued Visual Search task and the AX-CPT, the predictive relationship between these measures was not found in young and older adults. Neither response time PBI scores (AX-CPT), age or an PBI x Young vs Older Adult interaction significantly explained the variance in cueing ratios on singleton-absent trials in the Mostly Predictive block (Cued Visual Search). Correlations between cueing ratios and response time PBI scores, showed non-significant and weak negative (r = -.05) and positive (r = .18) associations in young and older adults, respectively. This suggests that individuals who were better at maintaining the cue in the Cued Visual Search task were not more likely to be better at maintaining the cue in the AX-CPT. Therefore, the behavioural profiles for cue-utilisation may be domain-specific within the Cued Visual Search task and the AX-CPT, which emphasises the importance of comparing experimental paradigms within the attentional (or cognitive) control field.

Importantly, age did not moderate the lack of relationship between both of the two investigated measures. Past research has suggested that older adults were unable to transfer cued task-switching training to the AX-CPT (Kray et al., 2020). In contrast measures of Track-It and the AX-CPT in young children aged five to six, showed a predictive relationship (Doebel et al., 2017). In the current study, the domain-specificity of cue-utilisation in the assessed measures applies both to young and aging populations. Thus showing that the measurement of this higher-order skill does not change with increasing age in adulthood.

One could argue that the translation or interpretation of the cue in the Cued Visual Search task and the AX-CPT is different. Research has suggested that the lack of transfer between measures of attentional (or cognitive) control may be due to differences in the translation of pictorial and symbolic cues (Kray et al., 2020). Central abstract cues which require greater stimulus-response translation have been shown to reduce cueing effects, particularly in aging populations (Hahn & Buttacio, 2018). However, the cue translation in the Cued Visual Search task (i.e. a featural cue which matches a feature in the search-display) as well as the AX-CPT (i.e. an animal) requires small levels of interpretation. This claim is strengthened by the cue-utilisation effects found in children as young as five (Chapter 5; Gonthier et al., 2019). Suggesting, differences in cue translation between the assessed measures is unlikely to explain the findings.

From a mechanistic perspective, the results indicate that cue-utilisation is not a domain-general process but domain-specific, as it is enacted differently in the Cued Visual Search task relative to the AX-CPT. As both of the measures encourage cue-utilisation through the use of context concerning the predictability of the cue, it was expected that early maintenance of this information was similar in both of these measures. Contrary to this, cue-utilisation in the AX-CPT has been associated with response anticipation and response conflict (Hämmerer et al., 2010; Lorsbach & Reimer, 2008; Rush et al., 2006). Building an expectation to anticipate making a response to probe “X” following cue “A”, can lead to high levels of conflict at the *response* level when probe “Y” is presented. Indeed, maintenance of cued information has been implicated in the dorsolateral prefrontal cortex in the AX-CPT (Braver et al., 2009; Mäki-Marttunen, Hagen & Espeseth, 2019), as well as the anterior cingulate cortex; a region heavily regarded in its functionality for monitoring the competition between prepotent but inappropriate responses (Barch et al., 1997; Carter et al., 1998). Resistance to response interference (P300) was also negatively correlated with response anticipation (CNV) in both young and older adults in a “go/no-go” variant of this task (Hämmerer et al., 2010). Thus suggesting that early maintenance of cue information in the AX-CPT may also be reflective of response anticipation which could lead to response interference on derivative trials.

In contrast, in the Cued Visual Search task, cue-utilisation leads to a visuo-spatial orienting response towards a cued feature in a search-display. Feature-based cueing, particularly colour cues, enhances visual evoked potentials for the cued feature at a global level across the entire visual field (Andersen et al., 2011; Martinovic et al., 2018). Thus increasing the readiness to make a volitional oculomotor response (Kramer et al., 1997). The colour cue provided information to enhance participants' *selection* of a stimulus feature related to the target (Laarni, 2001), critically, it did not provide information concerning the tilt of the target and so has less influence on helping participants to make a discriminatory judgement to the target. Hence, when attention is directed towards an invalid location, conflict is experienced at the *stimulus* level as the maintained cue provided incorrect information concerning the target's location (Shomstein & Gottleib, 2016). Stimulus interference caused by an invalid cue requires inhibition of this location at the perceptual level in order to disengage attention (Brodeur & Boden, 2000). Therefore, it is possible that cue-utilisation in the Cued Visual Search task builds anticipation for a stimulus feature but interference caused by invalid cues is managed at the stimulus level, as the cue does not inform participants about the tilt of the target.

Attentional Capture

The influence of cue-utilisation in the Cued Visual Search task on distractibility caused by the singleton distracter was assessed. Specifically, the analysis used in the current study was replicated from Chapter 3 to ease comparison. This meant that neutral trials in the Baseline block were assigned "valid" and "invalid" labels to match them to trials in the Mostly Predictive block which shared the same search-display. By keeping the search-display between block conditions constant, assigned trials in the Baseline block only differed in terms of cue colour; strengthening comparisons between cued (Mostly Predictive block) and Baseline performance. The analysis used to assess the aforementioned question, compared distraction ratios (singleton-present / singleton-absent median response times) on valid and invalid trials in the Mostly Predictive block to the assigned trials in the Baseline block. The results show no age-related differences in performance. Levels of distraction did not significantly differ between valid and invalid trials in the Mostly Predictive block, opposing evidence which suggests that aging incurs an inhibition deficit (Gazzaley & Clapp, 2012; West, 2000). In addition, distraction was reduced on assigned "valid" trials compared to assigned "invalid" trials in the Baseline block. This points to a variability within the Baseline block as participants experienced less distraction on one subset of trials labelled as "valid" (approx. 66.67%) compared to another subset of trials (approx. 33.33%) labelled as "invalid". Further consideration of this abnormality in the Baseline block will be discussed in Chapter 8|General Discussion (*see page 256*).

The findings point to the possibility that attentional capture is reduced on invalidly cued trials. Levels of distraction were reduced on invalid trials in the Mostly Predictive block relative to assigned "invalid" trials in the Baseline block. No differences were found between block conditions for valid trials. As trials between block conditions were matched based on the physical properties of the search-display, and thus yielding a stronger comparison measure, this finding could suggest that both young and older adults experienced less distraction when provided with an invalid cue. On this basis, it is possible that an invalid cue causes adults to further process items in the search-display which are relevant to the task-goal. Research has theorised that search following invalidly cued guidance of attention, leads to the inhibition of this location followed by serial search for the target (Theeuwes, 2010). Search is assumed to randomly move to each item in the search-display until the target is found (Treisman & Sato, 1990) or move towards the next salient item in the array based on saliency computations (Desimone & Duncan, 1995; Liesefeld et al., 2017; Theeuwes, 2010). This latter claim is said to be dependent on the size of the attentional window that is being evaluated for the target (Theeuwes, 2004). Cue guidance sets the attentional window at an invalid target location, whereby top-down processes can then adjust the size of this window based on an expectation associated with the target (Van der Stigchel et al., 2009).

In the current study, participants may have been guided to an invalid location and following inhibition of this item, adjusted the attentional window to encompass only coloured, circular items (vs monochromatic, edged items) to search for the target. As attention is theorised to be drawn to the most salient item within this window in a bottom-up fashion, reduced levels of distraction are expected if the singleton distracter was not included in the attentional window adjustment. Therefore, there is a possibility that invalid cues may lead to further processing by adjusting the attentional window in a top-down manner in order to search for the target in task-relevant items. However, it should be noted that this would also be expected for valid cues in the Mostly Predictive block as enhancing the signal for the colour feature related to the target, was expected to include the target location within the attentional window in the first sweep of selection. The exploratory analysis (Cue Validity x Age-Group ANOVA) which treated trials in the Baseline block as one level (averaged across labelled data), showed no differences in distractibility between trial types. Therefore, the conclusions drawn above are cautious and require greater reflection concerning the variability in the Baseline block.

The relationship between maintenance and inhibition skills was not found in both young and older adults. Specifically, maintenance of cued information in the Mostly Predictive block and inhibition of the singleton distracter in the Baseline block showed no predictive relationship with one another and this relationship was not moderated by age. This replicates and extends the findings from Chapter 3, by suggesting maintenance and inhibition abilities in Cued Visual Search are independent processes in both young and older adulthood. A similar finding was shown by Noonan et al. (2016) who found cueing the feature of the distracter (maintenance) was not related to inhibition of the distracter item. The independence of these processes could explain why valid cues could not facilitate performance by reducing attentional capture. In contrast, the reduced distraction on invalid trials may be a result of top-down processes at a late stage of processing (reactive control) to reorient attention to other colourful circles, rather than in relation to maintenance of the cue. Therefore, the interplay between both processes may be useful in Cued Visual Search but distinctive from one another during adulthood.

Colour Categorisation

Based on the discussion from analytical Chapter 4, I investigated whether individual differences in the ability to discriminate different categorical colours is related to cue-utilisation effects seen in the Mostly Predictive block of the Cued Visual Search task. It was expected that if cross-colour priming (attention is primed by a categorically different colour) plays a role in Cued Visual Search performance, a lower ability to discriminate between colour categories would explain a significant proportion of the variance in cueing ratios. Composite colour slopes were calculated by averaging linear slopes fitted to colour judgement data across six block conditions where colours ranged from one to a different colour category. This measure did not significantly predict cueing ratios on singleton-absent trials in the Mostly Predictive block, which suggests cross-colour priming is not a major determinant of cue-utilisation found in this condition. The relationship between composite slope scores and distraction ratios in the Baseline block was also investigated to further consider abnormalities in this condition. In this analysis, composite slope scores was weakly related to distraction ratios in the Baseline block in both age-groups. This suggests that cross-colour priming effects may not be able to explain the abnormalities found in the Baseline block in my assessment of attentional capture (*for more, see Limitations below*).

It should be noted however that averaging of linear slopes may have reduced the sensitivity of this measure as participants may be less discriminate in some colour ranges but not others. Closer inspection of the data showed that the range of linear slope scores as well as standard deviations between colour block conditions across all participants, were similar (*see Appendix 6.3*). Suggesting, participants discriminability between colours might have been alike across block conditions and close to ceiling.

Limitations

The measure of colour categorisation used in this study may not be particularly sensitive. The findings showed that average linear slopes did not significantly predict cue-utilisation effects in the Mostly Predictive block. In addition, colour discriminability did not explain the abnormalities between "valid" and "invalid" assigned trials in distraction ratios in the Baseline block. Linear slopes for each block condition were similar to one another and had little variability as shown by their standard deviations (*see Appendix 6.3*), which suggests that participants were not particularly worse at discriminating between colours in one block condition relative to others. That being said, each block condition of this task had a small number of trials (N = 15) which were further reduced and averaged into five bins of 3 trials. Previous research has also shown that older adults tend to find it difficult to discriminate between blue and yellow, as changes to the visual lens lead the appearance of items to be tinted in shades of yellow (Tamura & Sato, 2020). As the slope scores between young and older adults are similar for the yellow-blue block condition, this further brings into question whether the measure of colour categorisation was sensitive.

Past research tend to use staircase procedures based on the individual responses during the task (Wuerger, 2013): This is used to prevent ceiling effects as well as acquire a sensitive threshold for discriminating between colour categories. Data functions fitted to the data can then provide more clarity in the interval colour trials, whereby uncertainty in categorising colours as blue or green, for instance, can be represented in the slope rather than averaged. In general, it is possible that the colour categorisation task was not sensitive enough to examine individual differences in cross-colour discriminability, which could explain the lack of association with cue-utilisation in the Mostly Predictive block.

Future Directions

The task demands in the AX-CPT, specifically the cue-target delay period, may play a factor in explaining the differences to previous research. Older adults have been shown to use endogenous control in Kray et al. (2015) who used the same cue-target delay period (1500ms) as used in the replicated measure from Gonthier et al. (2019). In contrast, earlier findings showed older adults performed exogenously (reactively) in variants which had longer delay periods (4000ms; Braver et al., 2007). Paxton et al. (2008) investigated the influence of short vs long delay periods on aging populations, but showed mixed findings in that the behavioural findings showed slower response times but less error-prone responses on AY relative to BX trials in this age-group. This could point to the possibility of generalised slowing in older adults which influenced their response times but not their accuracy judgements. However, Paxton et al.'s (2008) fMRI findings suggested that older adults had enhanced activations for long delays in the prefrontal regions relative to young adults. Therefore, it is less understood whether cue-maintenance abilities in the AX-CPT are less robust under conditions of high working memory load. If so, it could be that older adults in the current chapter were able to anticipate the upcoming probe at short delay intervals which put less strain on their maintenance abilities. Further consideration is required to assess this claim.

The distance between the target and the singleton distracter require further consideration to understand the potential influence of this factor on attentional capture. Attentional window hypothesis suggests that participants will experience attentional capture if the singleton distracter falls in the focal area of attention, but this is less likely to occur in serial search when items are reviewed in small clusters (Belopolsky et al., 2007; Theeuwes, 2010; Van der Stigchel et al., 2009). This is grounded in the understanding that saliency computations based on bottom-up signals from items within an attentional window (small distances) would guide attention towards the most distinctive item (singleton distracter) in a "winner take all" manner (Desimone & Duncan, 1995). This would suggest that if attention is cued to the target and the singleton distracter is located adjacent (e.g. next quadrant over) to this item, larger attentional capture effects may occur relative to when the singleton distracter is located further away. In contrast to this, spatial surround suppression suggests that items which are located adjacent or immediately surrounding the focal area of attention, will be suppressed (Sundberg et al., 2009; Tsotsos, 1995; Wong-Kee-You et al., 2019). This makes an opposite prediction to the attentional window hypothesis, as it posits that participants will experience less attentional capture if the singleton distracter is located adjacent to the target relative to further away. Therefore, in my next assessment of cue-utilisation and attentional capture in Chapter 7, I plan to assess this question to understand whether it plays a role in attentional capture effects in both Cued Visual Search block conditions.

Critically, the search strategy may be an important factor to consider in cue-utilisation and attentional capture in the Cued Visual Search task. It is argued that featural targets (defined by one feature) which are presented in a homogenous display of non-targets can lead participants to utilise a *singleton detection strategy* (Bacon & Egeth, 1994; Lamy et al., 2004). This strategy depends on searching for a discrepancy or “odd one out” in the search-display to locate the target in a bottom-up fashion, which increases the likelihood of attentional capture by a singleton distracter (Bacon & Egeth, 1994; Eimer & Kiss, 2008). Previous research has suggested that attentional capture effects are disabled when search for the target is made more difficult by presenting heterogeneous non-target items (e.g. circle target, diamond, hexagon non-targets; Bacon & Egeth, 1994; Gaspelin et al., 2015, 2017). Conjunction search can also make search difficult for a target defined by two or more features that are shared by non-target items and has also been shown to enhance cue-utilisation in Cued Visual Search (Zhuang & Papathomas, 2011). It is possible that participants are less dependent on the cue and may switch to utilise a less effortful singleton detection strategy in the Mostly Predictive block. As such, I will further consider this claim in Chapter 7 to examine whether difficult search for a conjunctive target, leads to increased levels of cue-utilisation and reduced attentional capture effects in young adults.

Conclusion

The current study considered the role of aging on cue-utilisation in two measures of endogenous control. It was shown that cue-utilisation is preserved with increasing age suggestive of compensatory mechanisms at play. Specifically the results replicated previous research in showing this higher-order skill to be age-invariant in Cued Visual Search (Humphrey & Kramer, 1997; Greenwood & Parasuraman, 2004; Madden, 2007; Madden et al., 2004). However, the use of endogenous (or proactive) control is utilised but less robustly in aging populations in the AX-CPT, opposing previous findings which suggest that this strategy declines into the main use of exogenous (or reactive) control (Braver et al., 2007, 2009; Paxton et al., 2008). Interestingly, despite finding proficient cue-utilisation effects when measured independently, the predictive relationship between Cued Visual Search and AX-CPT performance was not found. Suggesting that endogenous control is a domain-specific skill, emphasising the importance of comparing performance across experimental paradigms. The evidence also suggests that attentional capture effects does not increase with age but greater clarity is required to further our understanding of this process.

Chapter 7: The Influence of Conjunction Search on Cue-Utilisation and Attentional Capture

Abstract

The previous chapters have shown endogenous cue-utilisation is not sufficient to prevent or reduce attentional capture from a singleton distracter. It is questionable however, whether this result was influenced by search for a singleton target (i.e. a tilted line amongst vertical lines). It is possible that search for a non-singleton or *conjunctive* target (i.e. a tilted exclamation point amongst tilted but inverted exclamation points) will enhance cue-utilisation and thus, reduce attentional capture. Young adults were asked to complete two block conditions of the Cued Visual Search task replicated from Chapter 6: 1) the Mostly Predictive block and 2) the Baseline block. Critically, participants were either assigned to the Easy Search group (singleton target as in Chapter 6) or the Difficult Search group where they searched for a conjunctive target. The findings showed that search difficulty did not influence cue-utilisation or attentional capture as, contrary to predictions, Difficult Search did not significantly increase cue-utilisation or reduce attentional capture relative to Easy Search. It is therefore possible that search difficulty plays a less prominent role in encouraging cue-use and distracter-inhibition. The relevant limitations and future directions for this research will be discussed.

Introduction

The previous chapters have highlighted a number of key findings. In Chapter 3, both nine- to 11-year-olds and adults (but not five- to- six-year-olds) were able to utilise cues endogenously in the Mostly Predictive block, yet they were unable to reduce attentional capture when the cue helped them find the target in this condition. Chapter 6 further considered this and provided participants with more time to encode and maintain the cue. The results differed from expectations as young and older adults were able to maintain the cues endogenously to guide attention in the Mostly Predictive block, but they may have experienced less distraction on invalid trials rather than valid trials. This could point to the possibility that reorienting attention at a late stage of processing on invalid trials could encourage further processing of task-relevant items (coloured circles) and avoidance of task-irrelevant items (black diamond; Moher & Egeth, 2012). In both chapters, the target was a singleton (i.e. tilted line) as it was defined by one feature which was not shared by the homogenous display of non-target lines (Bacon & Egeth, 1994). Research has suggested that difficulty for locating the target can play a crucial role in encouraging cue-utilisation (Greenwood & Parasuraman, 2004) as well as preventing attentional capture (Lamy et al., 2004). If search is easy (i.e. the target is a singleton), this could discourage cue-use and make participants more vulnerable to distraction (Gaspelin et al., 2015). The current chapter will consider whether cue-utilisation and attentional capture is influenced by search difficulty in young adults. First, I will discuss possible ways to manipulate search difficulty in Cued Visual Search and its influence on encouraging cue-use and distracter-inhibition.

Cue Utilisation

It is possible that a singleton target can reduce reliance on the cue for guiding attention in the Cued Visual Search task. By ensuring that the target is defined by a single feature which is not shared by the non-target items, participants are the able to locate this “pop out” item preattentively without deploying attentional resources (Wolfe et al., 1989; Wolfe, 2014). Evidence has shown that participants utilised the cue when the target was a singleton tilted line target presented amongst vertical lines in the Cued Visual Search task (Chapters 3, 5 & 6; Kiyonaga et al., 2012; Soto & Humphreys, 2007; Soto, Heinke, Humphreys & Blanco, 2005; Theeuwes et al., 2006). At the same time research has shown that when a memory probe, which questioned maintenance of the cue, was included in the trial sequence, participants had larger cueing effects (Kiyonaga et al., 2012; Soto & Humphreys, 2007). Indeed, participants in the memory probe condition produced a significantly larger and faster N2pc response to the cue relative to those in the no memory probe condition (Kumar, Soto & Humphreys, 2009). This suggests that a singleton target without a memory probe may not encourage active maintenance of the cue. It is possible that participants merely attended to the cue (Soto et al., 2008) or were less reliant on this early information as they were able to search for the singleton target "in the moment" it was presented. Therefore, it is less certain whether participants were switching between utilising the cue to locate the target and looking for the discrepancy in the display, as both strategies are viable options in Cued Visual Search with a singleton target.

Some research has shown that a non-singleton target can enhance cue-use and encourage active maintenance of this information for guiding attention, relative to a singleton target (Farell & Pelli, 1993; Zhuang & Papathomas, 2011). Feature search presents participants with a singleton target presented amongst a heterogenous display of non-target items (e.g. colour target: a black circle amongst white circles and crosses). Conjunction search presents participants with a non-singleton target that is defined by two or more features shared by non-target items (e.g. colour *and* shape target: a black circle amongst black crosses and white circles). Non-target items which share defining features of the target are assigned top-down attentional weights and so the target cannot be located preattentively but through serial search (Wolfe et al., 1989; Wolfe, 2014). Search for a conjunctive target is more difficult than feature search, as conjunction search requires participants to inhibit non-target items which share a task-relevant feature (Treisman & Sato, 1990).

In support of this claim, evidence has shown larger cueing effects in conjunction search, relative to feature search for both location and central cues that are mostly predictive (71% valid) of the target (Henderickx, Maetens and Soetens, 2010; Kawahara & Miyatani, 2001; Sobel, Pickard & Acklin, 2009). Even when provided with partial information about one of the features of the target, significant cue-utilisation has been shown in cued conjunction search tasks (Hannus, Bekkering & Cornelissen, 2020; Zhuang & Papathomas, 2011). This suggests that search is more difficult in conjunction search than feature search and so participants are more encouraged to maintain early cue information to facilitate their search or *featural binding* to locate the conjunctive target.

From the review of this research, it is understood that cue-utilisation is influenced by search difficulty. When the target is a singleton, participants may be less reliant on early cue information as they have the option to locate the target via pop out search (Kumar et al., 2009; Soto et al., 2008). Conjunction search increases search difficulty as the target is 1) not a singleton as it shares features with non-target items and 2) encourages serial search for the target. As a result, volitional cue-utilisation is encouraged to help participants find the target without serially searching for the target (Kawahara & Miyatani, 2001; Sobel et al., 2009). Next, I will consider the influence of search difficulty on attentional capture.

Attentional Capture

Research has argued that a target which "pops out" in the search-display, can encourage adults to utilise a *singleton detection strategy* which puts them more at risk of attentional capture (Bacon & Egeth, 1994; Lamy et al., 2004). As previously discussed, this strategy enables participants to locate the target in a bottom-up fashion based on saliency computations, by searching for the "odd one out" or discrepancy in the display rather than searching for the specific feature of the target (Eimer, Kiss & Nicholas, 2011; Lamy et al., 2004). Evidence has shown that adults experienced attentional capture when the target was presented amongst a homogenous display of non-target items (e.g. circle target amongst diamonds; Bacon & Egeth, 1994; Gaspelin et al., 2015, 2017). But attentional capture was prevented when the target was presented amongst a heterogenous display of non-targets (*feature search*; e.g. circle target amongst different shaped items; Bacon & Egeth, 1994; Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017; Jannati et al., 2013). By manipulating the appearance of non-target items, this reduced the local contrast between the target and the surrounding items (i.e. reduced its bottom-up “pop out” saliency; Treisman & Sato, 1990; Wolfe, 2014). This manipulation can also reduce preattentive grouping and early rejection of homogenous non-target items and therefore, reduce the likelihood of attention being directed towards the most salient item in the search-display (i.e. the singleton distracter; Humphreys, 2016; Humphreys & Müller, 1993). Therefore, participants are more encouraged to maintain the task-goal to search for a specific feature and become less reliant on a singleton detection strategy.

In contrast to this claim, manipulating the non-target items may be dependent on the density of the search-display (i.e. set size) as well as the feature dimension. Research has shown that participants experienced large capture effects (225ms) when the singleton distracter was a 45° oriented line and the target was a less salient 12° oriented line presented amongst a dense array of vertical lines (Liesefeld et al., 2017). In this instance, the local contrast of the 45° singleton distracter was enhanced by a large set size of vertical lines. However, it is reasonable to suggest that a small set size (e.g. 3 items) could still lead a 45° line to pop out in the search-display when presented amongst a vertical non-target and differently oriented non-target line. Thus, by solely manipulating non-target items in my Cued Visual Search task may not be enough to prevent participants from searching for the target in a bottom-up fashion.

From the discussed research, it is known that cue-utilisation is enhanced when searching for a conjunctive target (Kawahara & Miyatani, 2001), which could in turn influence the level of attentional capture experienced. To my knowledge, it is scarcely understood whether attentional capture can be reduced or prevented in conjunction search. That being said, Bacon and Egeth’s (1994) argument could apply to conjunction search, as this type of search ensures participants cannot locate the target based on saliency computations and so requires maintenance of a task-goal (Sobel et al., 2009). As some evidence has shown that providing a task-goal concerning distracter information benefited performance in conjunction search; this suggests that the provision of a task-goal can reduce distraction in this type of search (Bacon & Egeth, 1997). From the discussion, previous research has shown 1) feature search can prevent attentional capture and 2) cue-utilisation is enhanced when the target is defined by a conjunction of features rather than a single feature. Hence it is reasonable to suggest that when search is more difficult (i.e. a conjunctive target), participants require more assistance to help them locate the target. This may encourage endogenous cue-utilisation and thereby increase the task-relevant signal for the cued item, which in turn could reduce the task-irrelevant signal of the singleton distracter (Sawaki & Luck, 2010; Luck, Gaspelin, Folk, Remington & Theeuwes, 2021).

It should also be noted that past studies have failed to directly compare search types in attentional capture research (e.g. singleton vs feature search; Bacon & Egeth, 1994; Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017; Gaspelin & Luck, 2018; Jannati et al., 2013). It is therefore questionable to what *extent* search difficulty can influence attentional capture as well as how beneficial this manipulation can be for encouraging endogenous control. Therefore, the current chapter will aim to compare Easy search (singleton target used in previous chapters) and Difficult search (conjunctive target) to understand whether search difficulty influences endogenous cue-utilisation and attentional capture in adults.

The Current Study

The current study had three aims. First, I aimed to understand if cue-utilisation is influenced by search difficulty. Second, I investigated whether attentional capture can be reduced or prevented when search is difficult. Third, I considered how the distance between the target and the singleton distracter could influence attentional capture and whether this interacted with my manipulated factors. I asked participants to complete two conditions (Mostly Predictive block and Baseline block) of the Cued Visual Search task replicated from Chapter 6. Search difficulty was manipulated by assigning participants to one of two groups. The Easy Search group completed the version of the task used in Chapter 6 where they searched for a singleton tilted line target presented amongst a homogenous display of vertical lines (*see Participants for more detail*). The Difficult Search group were asked to search for a tilted exclamation point (!) presented amongst a heterogenous display of tilted but inverted exclamation points (i). This group searched for a conjunctive target which was defined by form and orientation.

If search difficulty influenced cue-utilisation, it is expected that cueing ratios in the Mostly Predictive block would be larger in the Difficult Search group relative to the Easy Search group (Hannus et al., 2020; Kawahara & Miyatani, 2001; Sobel et al., 2009). This would show that participants are more encouraged to maintain endogenous cues to guide attention when search is difficult and so they are less likely to use a singleton detection strategy. In relation to attentional capture, it is predicted that distraction ratios on valid trials in the Mostly Predictive block will be reduced relative to Baseline for participants in the Difficult Search group but not the Easy Search group. This would suggest that by encouraging reliance and maintenance of cue-information to assist search for a difficult target item, attention towards task-irrelevant distractions is reduced.

Lastly, in Chapter 2 I showed that when the target and the singleton distracter was in the same quadrant, this led to better accuracy when responding to the target. I did not compare near (e.g. neighbouring quadrant) and far distance effects and whether this influences performance in Cued Visual Search. I considered this for my third aim as an additional exploratory question. There were two predictions for whether the distance between the target and the singleton distracter influences attentional capture. Attentional window hypothesis would predict that smaller distances would lead to greater capture effects as the singleton distracter would “win” attention based on saliency computations (Belopolsky et al., 2007; Desimone & Duncan, 1995; Theeuwes, 2010). In contrast, spatial surround suppression would predict that smaller distances could lead to less capture if the focal of attention is guided towards the cued target and adjacent items (i.e. in the neighbouring quadrant) are suppressed (Tsotsos, 1995; Wong-Kee-You et al., 2019).

Method

The hypotheses and analyses for this study were pre-registered on the Open Science Framework (*see Appendix 7.1*).

Participants

Seventy three participants took part in this study after exclusion. The aim of this study was to compare performance in the previous version of the Cued Visual Search task where the target was a singleton, to a new version of this task where the target was not a singleton (i.e. a conjunctive target). Due to this, young adult participants who were assigned to the Easy Search group were the same participants from Chapter 6[32]. Forty three participants were assigned to the Easy Search group and 30 participants were assigned to the Difficult Search group (*see Table 7.1 overleaf*). All participants were undergraduate and postgraduate psychology students from the University of Nottingham. As in the previous chapter, one participant was excluded from the Easy Search group as they reported to have been formally diagnosed with visual floaters. All participants reported to have normal or corrected-to-normal vision and reported to have had no formal diagnosis of colour blindness, visual impairment, Autistic Spectrum Disorder and/or Attention Deficit and Hyperactivity Disorder.

Power for the current study was based on the power analysis conducted for Chapter 6[33]. This showed that 55 participants were required in each group to acquire a small to medium effect size at an alpha criterion of .01. Although this power analysis was based on a different aim than the

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[32] It should be noted that participants in the Easy Search group took part in two additional tasks (Colour Categorisation & the AX-CPT) which the Difficult Search group did not complete due to different aims.

[33] This power analysis was to assess if cue-utilisation in Cued Visual Search would be predicted by AX-CPT performance. This powered for the ANOVA for R^2 to deviate from 0 when nine predictor variables were included in the model.

current study, this sample size is more than adequate relative to previous research which compared cue-utilisation between conjunction search and other search types (sample sizes ranged from 16-20 participants per group; Hendrickx et al., 2010; Kawahara & Miyatani, 2001). However it should be noted that due to unprecedented circumstances with COVID-19, data collection for this study was discontinued and is only partially complete. This study was granted ethical approval from the University of Nottingham School of Psychology Ethics Committee and was also part of a third year undergraduate dissertation project (*see Design for more details*).

Table 7.1. Participant demographic information.

	Easy Search Group	*Difficult Search Group*
N	43	30
M age (SD) (years, months)	19.34 (1.60)	20.53 (1.07)
Age range (years, months)	18.80 – 25.92	18.58 – 22.17
Gender Identity (m : f)	11.63% : 88.37%	20% : 80%
Ethnicity	62.79% White, 16.28% South Asian, 16.28% Chinese, 2.33% Black, 2.33% Mixed Ethnic Groups	96.67% White, 3.33% Other
Bilingual	48.84%	10%

Note: M = mean; SD = standard deviation; m = male; f = female.

Design

A mixed design was used. The Cued Visual Search task was replicated from Chapter 6, with one key difference made in the current study. This difference was the Search group which changed the appearance of the target and non-target lines in the Difficult Search group. Participants in the Easy Search group were required to search for a tilted line (singleton) target amongst a homogenous display of vertical non-target lines. In contrast to this, participants in the Difficult Search group were required to search for a tilted exclamation point (conjunctive) target amongst a heterogenous display of tilted but inverted non-target lines. Here, the target is defined by a conjunction of features with respect to searching for a line where the point was at the bottom (form dimension) and was tilted (orientation dimension). The non-target lines shared a feature with the target line with respect to similarities in its form and the orientation (*see Stimuli next*). Two researchers were involved in the data collection for this study. I conducted the data collection for participants in the Easy Search group and a third year undergraduate student led the data collection for participants in the Difficult Search group.

As in the previous chapter, participants in both groups completed two block conditions of the Cued Visual Search: the Mostly Predictive block (66.67% valid trials, 33.33% invalid trials) and the Baseline block (100% neutral trials). Singleton Presence was manipulated so that the singleton distracter was presented on 41.67% of the trials in each block condition. Trial proportions were replicated from the previous chapters.

Stimuli

All elements of the Cued Visual Search task, except from the target and non-target lines presented to the Difficult search group, were replicated from Chapter 6 (*see Figure 7.1 overleaf*). As in the previous chapters, participants in the Easy Search group were presented with a white line target (0.08° width x 0.41° height) which was tilted 45° clockwise and anticlockwise an equal number of times. The non-target items consisted of two white vertical lines. Participants in the Difficult Search group were presented with a white exclamation point (!; 0.08° width x 0.41° height) which was equally tilted 45° clockwise and anticlockwise. The non-target items had the same characteristics as the target line but the important difference between these items, was that the non-target items were inverted. Therefore, participants had to search for a tilted target where the dot was at the bottom of the line (!) and they had to ignore the tilted non-targets where the dot was at the top of the line (¡). On each trial, one non-target shared the same orientation as the target. For both groups, in the search-display two coloured circles

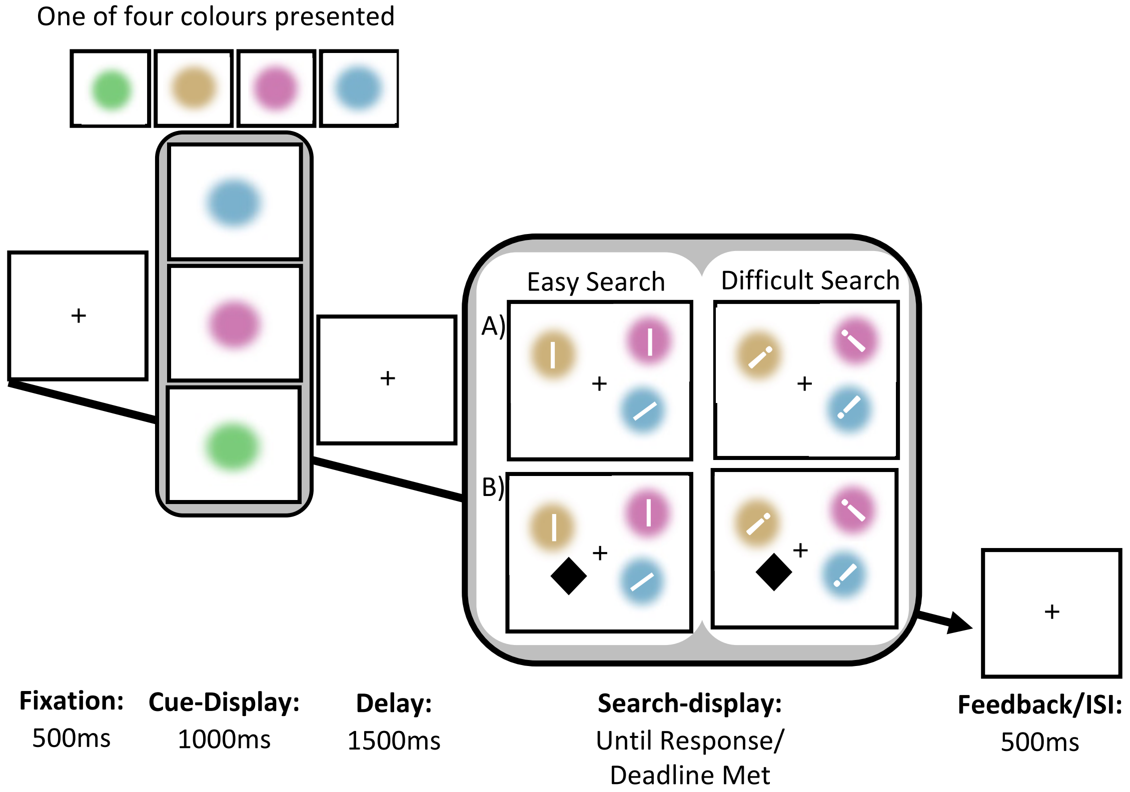

Figure 7.1. Schematic representation of the Cued Visual Search task with time durations. The Search-Display depicts a singleton-absent (A) and singleton-present (B) trial. In this example, if the cue was valid, a blue cue would guide participants' attention towards the tilted line (Easy Search) or exclamation point (Difficult Search) target in the blue circle. If the cue was invalid, a pink or a yellow cue would guide attention away from the target. If the cue was neutral, a green cue was expected to not guide attention towards or away from the target as this colour is not present in the search-display.

contained a non-target line and the remaining coloured circle contained the target line in its centre. The target line was presented in each quadrant of the screen an equal number of times.

Apparatus & Materials

All stimuli were created and run using PsychoPy2 version 1.85 (Peirce, 2019). As in previous Chapters 3-6, the stimuli were presented on a LCD iiyama ProLite B2206WS monitor (34.05° width x 23.06° height) which had been calibrated for luminance and colour and had a Mac Mini core processor. An Apple keyboard was used to record responses.

Procedure

Two researchers were involved in data collection. To ensure consistency, the instructions from Chapter 6 were used to explain the task to both Search groups. Participants in both groups were notified that the task was designed for children and adults and was known as the “Let’s Find Dory” game, whereby Dory is lost and the aim is to follow her trail (i.e. target line) and her clues might help them to find her trail. This context was provided before explaining the task in more detail to avoid confusion. The key difference in instructions between Search groups was regarding the target line. The Easy Search group were instructed that they needed to search and respond to a tilted line presented amongst straight lines. The Difficult Search group was instructed that they needed to search and respond to a tilted exclamation point where the dot was at the bottom of the line, presented amongst tilted but upside down exclamation points where the dot was at the top. Both groups were asked to respond to the tilt (L/R) or the target line as fast and accurately as they could using the ‘z’ and the ‘/’ keys, which had stickers placed on them to assist finger placement.

Both groups completed the Response Practice (no cue) phase and the Cue Practice phase. Both phases could be repeated following the same criteria used in all previous chapters. No participants repeated any practice phase more than three times and so no participants were excluded on this basis. Participants completed 144 experimental trials with three break periods in each block condition. The order of the block conditions was counterbalanced between participants[34].

Results

Data Processing

As in the previous chapters, neutral trials in the Baseline block were assigned “valid” and “invalid” variable names to match the Mostly Predictive block. This ensured that the search-display between trials in each block condition were kept constant but the cue colour was different.

The data were filtered of the first trial of the experimental phase and the first trial following a break period. Trials were removed if: participants failed to make a response within the deadline (Easy Search Group: .25%; Difficult Search Group: .68%) and the singleton distracter was presented in the same quadrant as the target (Easy Search Group: 8.33%; Difficult Search Group: 8.33%). Inaccurate trials were filtered from the analysis of response times. The data was assessed for multivariate outliers by calculating a Mahalanobis’ Distance across all response time and accuracy variables for participants in each group. No participants met the criteria for a multivariate outlier (cumulative probability > .001) and so no participants were excluded from the analyses[35].

Analysis

For the **first aim**, I investigated whether search difficulty influenced cue-utilisation. For untransformed data, see Tables 7.2 and 7.3. To measure cue-utilisation, I calculated cueing ratios (median response time: invalid /

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[34] This counterbalancing took into consideration the AX-CPT completed by the Easy Search group.

[35] In Chapter 6, one participant from the young adult age-group was excluded from all analyses as they were a multivariate outlier in the AX-CPT. They were not an outlying participant in the Cued Visual Search task and so they were included in the current study within the Easy Search group.

Table 7.2. Untransformed average median response times, standard error and 99% confidence intervals across block, cue validity and singleton-presence across two search groups.

			Easy Search Group			*Difficult Search Group*		
			M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Mostly Predictive block	*Valid*	*Absent*	.66	.02	.62, .71	.99	.05	.86, 1.12
		Present	.69	.02	.64, .74	1.02	.05	.89, 1.16
	Invalid	*Absent*	.87	.03	.78, .96	1.37	.05	1.22, 1.52
		Present	.90	.03	.82, .97	1.37	.04	1.25, 1.49
Baseline block	*Valid*	*Absent*	.72	.02	.66, .78	1.27	.06	1.11, 1.42
		Present	.74	.02	.69, .79	1.27	.05	1.13, 1.41
	Invalid	*Absent*	.70	.02	.65, .76	1.23	.06	1.07, 1.39
		Present	.76	.02	.70, .82	1.26	.05	1.11, 1.40

Note: M – mean; SE – standard error; 99% CI – 99% confidence intervals [lower, upper bound].

Table 7.3. Untransformed average accuracy, standard error and 99% confidence intervals across block, cue validity and singleton-presence across two search groups.

			Easy Search Group			*Difficult Search Group*		
			M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Mostly Predictive block	*Valid*	*Absent*	.98	.003	.97, .99	.97	.01	.94, .99
		Present	.98	.01	.96, .99	.97	.01	.95, .99
	Invalid	*Absent*	.96	.01	.94, .97	.93	.03	.87, .99
		Present	.96	.01	.95, .98	.94	.01	.90, .98
Baseline block	*Valid*	*Absent*	.97	.004	.96, .98	.93	.01	.91, .96
		Present	.97	.01	.95, .98	.94	.02	.90, .99
	Invalid	*Absent*	.98	.01	.97, 1.00	.96	.01	.92, 1.00
		Present	.97	.01	.95, .99	.95	.02	.91, 1.00

Note: M – mean; SE – standard error; 99% CI – 99% confidence intervals [lower, upper bound].

valid; mean accuracy: valid / invalid) using data from all trials (singleton-absent & singleton-present trials) in each block condition. Separate Block (Mostly Predictive, Baseline) x Singleton Presence (absent, present) x Search Group (Easy Search, Difficult Search) mixed ANOVAs were conducted on average cueing ratios for response time and accuracy. This analysis differs from the previous Chapter 6 assessing cue-utilisation, as it includes Singleton Presence as a factor to consider whether cueing ratios changed as function of whether the singleton distracter was present or absent from the search-display[36]. For the aim of this analysis, if participants are maintaining the cue to guide attention, it is expected that cueing ratios will be larger in the Mostly Predictive block relative to Baseline. Critically, it is predicted that participants in the Difficult Search group will have larger cueing ratios in the Mostly Predictive block compared to those in the Easy Search group.

For the **second aim**, I considered the influence of search difficulty on attentional capture. Distraction ratios were calculated (median response time: singleton-present / singleton-absent; mean accuracy: singleton-absent / singleton-present), whereby ratios above 1 suggest high levels of attentional capture. Separate Block x Cue Validity (valid, invalid) x Search Group mixed ANOVAs were conducted on average cueing ratios for response time and accuracy. If participants experienced reductions in attentional capture it was expected that they would have smaller distraction ratios on valid trials in the Mostly Predictive block, compared to Baseline. It was predicted that this pattern of results would be found for participants in the Difficult Search group as they are expected to have better maintenance of the cue and task-goal, relative to the Easy Search group.

Lastly, for the **third aim**, the distance between the target and the singleton distracter will be considered. If distance effects influences attentional capture, participants in the Difficult Search group may only reduce distraction for far distances but not for near distances between the target and

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[36] The influence of Singleton Presence on cue-utilisation was also assessed in Chapter 3 as a supplementary analysis (*see Appendix 3.1*), which showed no influence of this factor on cue-use across age-groups.

the singleton distracter (*attentional window hypothesis*; Theeuwes, 2010). Or they may only reduce distraction for near distances but not far distances, as items immediately surrounding the focal of attention (i.e. the cued target) are inhibited (*spatial surround suppression*; Tsotsos, 1995). For all analyses, an alpha criterion of .01 was used and simple main effects with Bonferroni correction was conducted for all significant interactions.

Cue-Utilisation

Response Time

The Block x Singleton Presence x Search Group interaction was not significant ($F(1, 71) = .58$, $p = .449$, $\eta_p^2 = .01$; *see Figure 7.2 overleaf*). The Block x Search Group interaction ($F(1, 71) = 6.45$, $p = .013$, $\eta_p^2 = .083$; *see Figure 7.3 overleaf*) and Block x Singleton Presence interaction ($F(1, 71) = 5.87$, $p = .018$, $\eta_p^2 = .08$) both did not reach significance. The remaining interaction term Singleton Presence x Search Group also was not significant ($F(1, 71) = .63$, $p = .429$, $\eta_p^2 = .01$). The main effects of Singleton Presence ($F(1, 71) = .11$, $p = .737$, $\eta_p^2 = .002$) and Search Group ($F(1, 71) = 2.78$, $p = .10$, $\eta_p^2 = .04$) were non-significant. However, the main effect of Block was significant ($F(1, 71) = 221.17$, $p < .001$, $\eta_p^2 = .76$) and showed participants had larger cueing ratios in the Mostly Predictive block compared to the Baseline block.

Although the Block x Search Group interaction did not reach significance at the alpha criterion of .01, it was close and met the criteria for $p < .05$. Therefore, as it was one of the main aims of the study and the current sample was underpowered, I ran further analyses for exploratory purposes. Simple main effects, with Bonferroni correction, showed that participants in both Easy and Difficult Search groups had larger cueing ratios in the Mostly Predictive block, compared to the Baseline block (both *ps* < .001). Critically, participants in the Difficult Search group had larger cueing ratios in the Mostly Predictive block than those in the Easy Search group ($p = .031$). No significant difference was found in cueing ratios between Search groups for the Baseline block ($p = .149$).

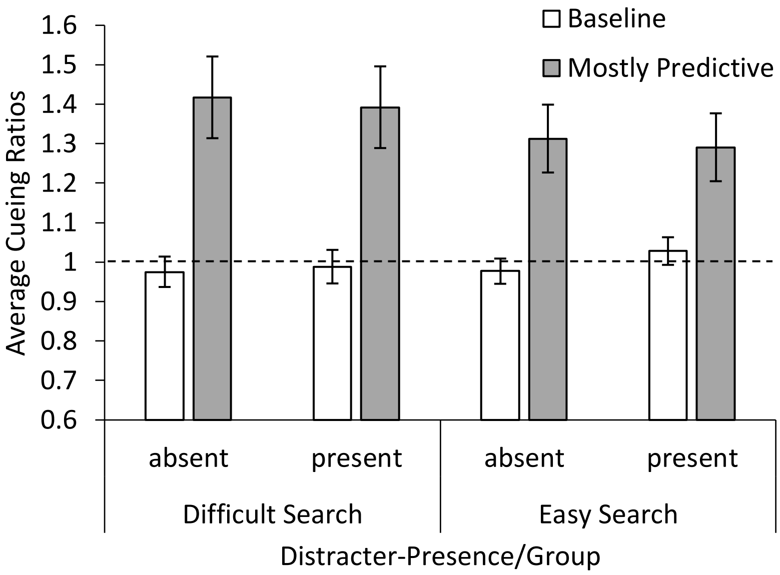

Figure 7.2. Average cueing ratios on singleton-absent and singleton-present trials in the Baseline block (white bars) and Mostly Predictive block (grey bars) across Easy and Difficult Search groups. Error bars represent 99% confidence intervals.

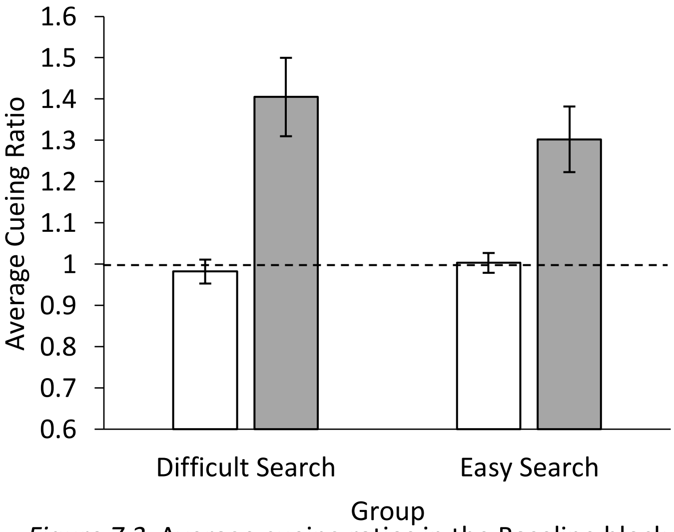

Figure 7.3. Average cueing ratios in the Baseline block (white bars) and Mostly Predictive block (grey bars) across Easy and Difficult Search groups. Error bars represent 99% confidence intervals.

Accuracy

The Block x Singleton Presence x Search Group interaction was not significant (*F*(1, 71) = .306, *p* = .582, η_p^2 = .004; *see Table 7.4*). The interactions terms, Block x Search Group (*F*(1, 71) = 3.70, *p* = .058, η_p^2 = .05; *see Table 7.5*), Block x Singleton Presence (*F*(1, 71) = 2.25, *p* = .138, η_p^2 = .03) and Singleton Presence x Search Group (*F*(1, 71) = .01, *p* = .914, $\eta_p^2 < .001$) were non-significant. The main effects of Singleton Presence (*F*(1, 71) = .11, *p* = .741, η_p^2 = .002) and Search Group were also not significant (*F*(1, 71) = 1.37, *p* = .245, η_p^2 = .019). Replicating the response time analysis, a significant main effect of Block was found (*F*(1, 71) = 21.25, *p* < .001, η_p^2 = .239). This showed participants had larger cueing ratios in the Mostly Predictive block relative to the Baseline block.

Table 7.4. Average Cueing Ratio for accuracy, (Standard Error and [99% Confidence Intervals of the Mean]) across Singleton-Absent and Singleton-Present trials and search groups.

		Easy Search Group	*Difficult Search Group*
Mostly Predictive block	*Absent*	1.02 (.02 [.97, 1.08])	1.01 (.03 [1.00, 1.13])
	Present	1.01 (.01 [.99, 1.04])	1.04 (.01 [1.01, 1.07])
Baseline block	*Absent*	.99 (.01 [.97, 1.01])	.98 (.01 [.96, 1.01])
	Present	.99 (.01 [.96, 1.03])	1.00 (.02 [.96, 1.04])

Note: M = Mean; SE = Standard Error; 99% CI = 99% Confidence Intervals.

Table 7.5. Average Cueing Ratio for accuracy, (Standard Error and [99% Confidence Intervals]) for the Mostly Predictive and Baseline blocks across Easy and Difficult Search groups.

	Easy Search Group			*Difficult Search Group*		
	M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Baseline	.99	.01	.97, 1.01	.99	.01	.96, 1.01
Mostly Predictive	1.02	.01	.98, 1.06	1.05	.02	1.01, 1.10

Note: M = Mean; SE = Standard Error; 99% CI = 99% Confidence Intervals.

Overall, the findings suggest that cue-utilisation was enhanced in the Mostly Predictive block relative to the Baseline block (as expected). Exploratory analyses suggested that cue-utilisation was greater for those in the Difficult Search group compared to the Easy Search group at the $p < .05$ level.

Attentional Capture

Response Time

For the analysis on distraction ratios, the Block x Cue Validity x Search Group interaction was not significant ($F(1, 71) = .44$, $p = .509$, $\eta_p^2 = .01$; *see Figure 7.4*). The Block x Cue Validity interaction also did not meet significance ($F(1, 71) = 6.72$, $p = .012$, $\eta_p^2 = .09$; *see Figure 7.5 overleaf*). The main effects for Block ($F(1, 71) = .69$, $p = .41$, $\eta_p^2 = .01$) and Cue Validity ($F(1, 71) = .76$, $p = .387$, $\eta_p^2 = .01$) were also non-significant. All other main effects and interactions were not significant.

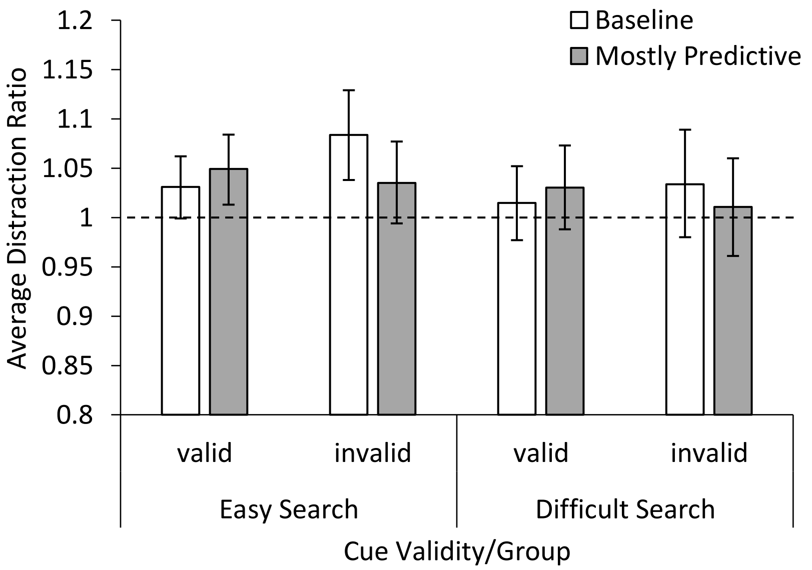

Figure 7.4. Average distraction ratios for the Baseline block (white bars) and Mostly Predictive block (grey bars) across valid and invalid trials and search groups. Error bars represent 99% confidence

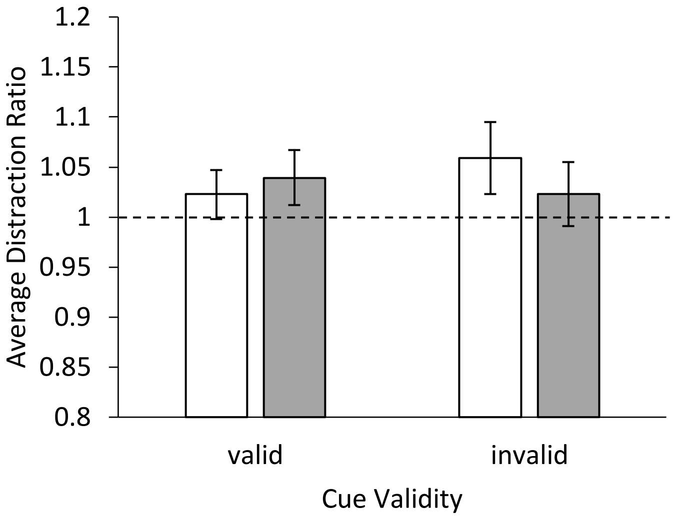

Figure 7.5. Average distraction ratios for valid and invalid trials assigned to the Baseline block (white bars) and in the Mostly Predictive block (grey bars). Error bars represent 99% confidence intervals.

Accuracy

A non-significant Group x Cue Validity x Block interaction was found ($F(1, 71) = .02$, $p = .884$, $\eta_p^2 < .001$; *see Table 7.6*). The Block x Cue Validity interaction was also not significant ($F(1, 71) = 1.60$, $p = .209$, $\eta_p^2 = .02$; *see Table 7.7*). The main effects for Block ($F(1, 71) = 2.21$, $p = .141$, $\eta_p^2 = .03$), Cue Validity ($F(1, 71) < .001$, $p = .992$, $\eta_p^2 < .001$) and Search Group ($F(1, 71) = .94$, $p = .335$, $\eta_p^2 = .01$) were non-significant. All other interactions were non-significant.

Table 7.6. Average Distraction Ratio for accuracy, (Standard Error and [99% Confidence Intervals of the Mean]) across Valid and Invalid trials and search groups.

		Easy Search Group	*Difficult Search Group*
Mostly Predictive block	*Valid*	1.00 (.01 [.98, 1.02])	1.00 (.01 [.97, 1.02])
	Invalid	.99 (.01 [.96, 1.02])	.99 (.01 [.95, 1.02])
Baseline block	*Assigned Valid*	1.01 (.01 [.98, 1.03])	1.00 (.01 [.97, 1.02])
	Assigned Invalid	1.01 (.01 [.99, 1.04])	1.01 (.01 [.98, 1.04])

Table 7.7. Average Distraction Ratio for accuracy, (Standard Error and [99% Confidence Intervals]) across Valid and Invalid trials and Block conditions.

	Baseline block			*Mostly Predictive block*		
	M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
Valid Trials	1.00	.01	.98, 1.02	1.00	.01	.98, 1.01
Invalid Trials	1.01	.01	.99, 1.03	.99	.01	.97, 1.01

Note: M = mean; SE = standard error; 99% CI = 99% confidence intervals.

In general, the results suggest that participants in the Difficult Search group were unable to reduce distraction as predicted on valid trials in the Mostly Predictive block relative to the Baseline block. This suggests search difficulty did not significantly influence attentional capture.

Distance Effects - Exploratory

This analysis explored whether the distance between the target and the singleton distracter influenced attentional capture effects. For singleton-present trials, I calculated the distance between the target line and the singleton distracter using their coordinate values (distance = $\sqrt{x^2 + y^2}$). The distance values ranged from 5.16° (6.32cm) to 9.18° (11.31cm). I used median split (median = 6.72° or 8.25cm) to code singleton-present trials as “near” (distance <= 6.72°) or “far” (distance > 6.72°). I then transformed the data into distraction ratios for each participant. Using median response times, I calculated: singleton-present on near trials / singleton-absent and singleton-present on far trials / singleton-absent. Using mean accuracy data, I calculated: singleton-absent / singleton-present on near trials and singleton-absent / singleton-present on far trials. Separate Block x Cue Validity x Distance (near, far) x Search Group mixed ANOVAs were conducted on average distraction ratios for response time and accuracy data.

Response Time

The Block x Cue Validity x Distance x Search Group interaction was not significant ($F(1, 71) = 2.24$, $p = .139$, $\eta_p^2 = .03$; *see Figure 7.6 overleaf*). The Block x Cue Validity x Distance interaction was also non-significant ($F(1, 71) = .01$, $p = .918$, $\eta_p^2 < .001$). The Cue Validity x Distance interaction did not reach significance ($F(1, 71) = 5.73$, $p = .019$, $\eta_p^2 = .08$; *see Figure 7.7*). The main effect of Distance was also not significant ($F(1, 71) = .11$, $p = .744$, $\eta_p^2 = .002$). All other main effects and interactions were non-significant.

Accuracy

The results replicate the findings above, as the Block x Cue Validity x Distance x Search Group interaction was not significant ($F(1, 71) = .03$, $p = .86$, $\eta_p^2 < .001$; *see Table 7.8*). The interaction terms Block x Cue Validity x Distance ($F(1, 71) = .19$, $p = .663$, $\eta_p^2 = .003$) and Cue Validity x Distance ($F(1, 71) = .63$, $p = .431$, $\eta_p^2 = .01$) were non-significant. The main effect of Distance did not meet significance ($F(1, 71) = 3.79$, $p = .056$, $\eta_p^2 = .05$). All other main effects and interactions were not significant.

Table 7.8. Average Distraction Ratio, Standard Error and 99% Confidence Intervals for the Mostly Predictive and Baseline blocks across valid and invalid trials, near and far target-distracter distances and search groups.

		Easy Search Group			*Difficult Search Group*		
		M	*SE*	*99% CI*	*M*	*SE*	*99% CI*
		Near Trials					
Mostly Predictive	Valid	1.01	.01	.98, 1.04	1.00	.01	.97, 1.03
	Invalid	1.00	.01	.97, 1.04	1.00	.02	.96, 1.05
Baseline	Valid	1.00	.01	.98, 1.03	1.00	.01	.97, 1.04
	Invalid	1.01	.01	.98, 1.04	1.02	.01	.98, 1.05
		Far Trials					
Mostly Predictive	Valid	1.00	.01	.98, 1.02	.99	.01	.96, 1.01
	Invalid	.98	.01	.95, 1.02	.98	.02	.94, 1.02
Baseline	Valid	1.01	.01	.98, 1.04	1.00	.01	.96, 1.04
	Invalid	1.01	.01	.98, 1.04	1.01	.01	.97, 1.04

Note: M = Mean; SE = Standard Error; 99% CI = 99% Confidence Intervals.

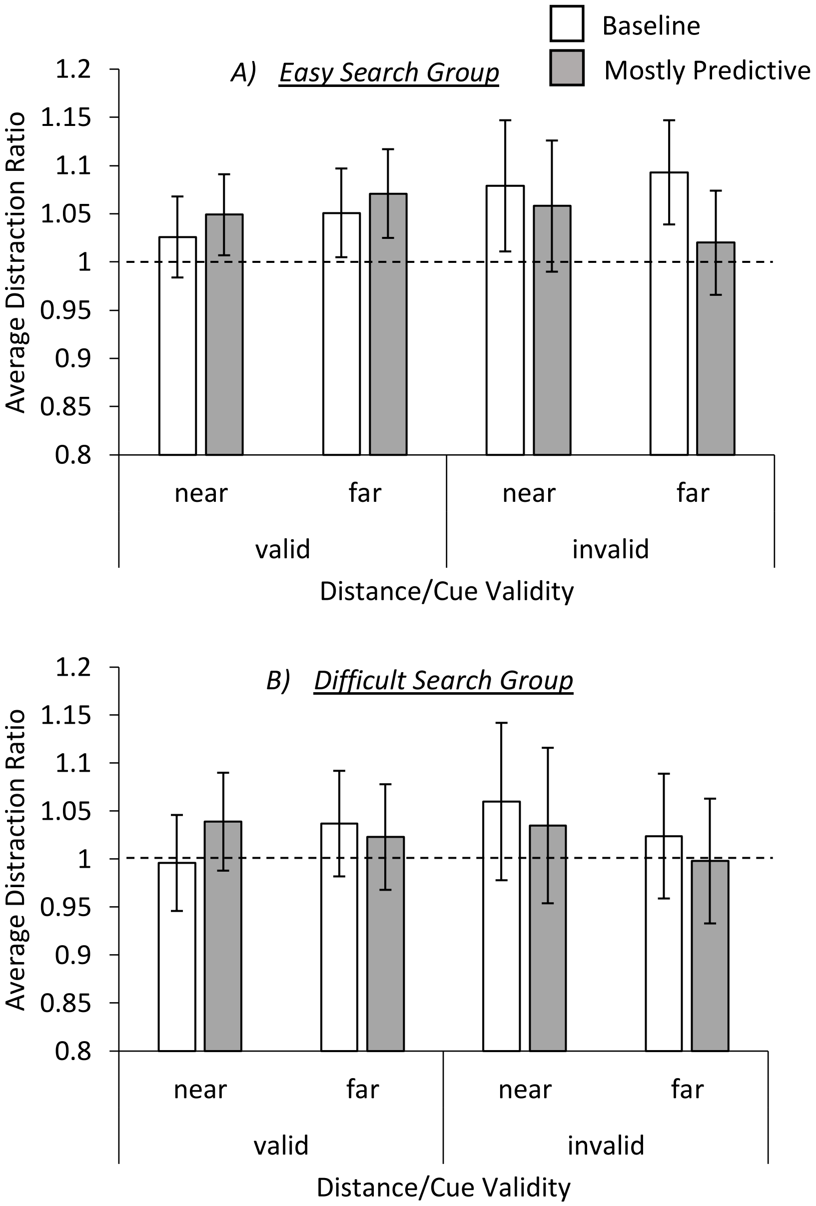

Figure 7.6. Average distraction ratios for the Baseline block (white bars) and the Mostly Predictive block (grey bars) on valid vs invalid trials when the singleton-distracter is near vs far from the target in the Easy Search (A) and Difficult Search (B) groups. Error bars represent 99% confidence intervals.

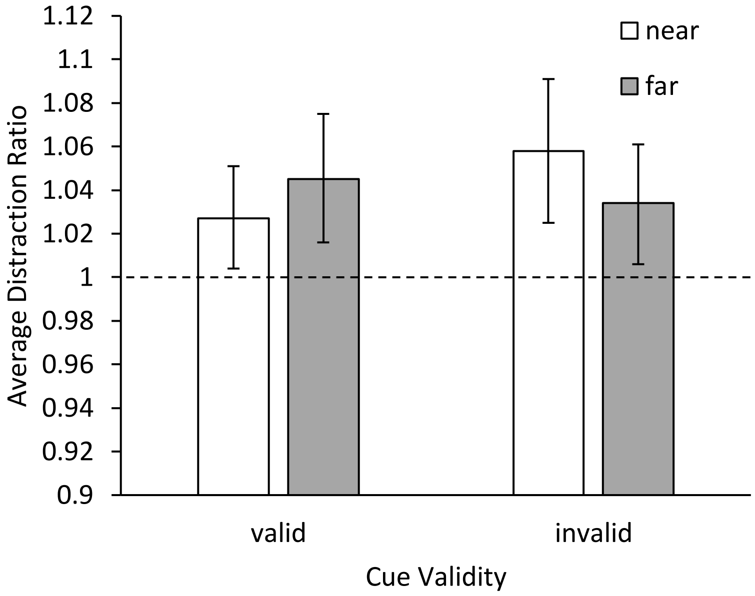

Figure 7.7. Average distraction ratios on valid and invalid trials for when the singleton distracter was near (white bars) or far (grey bars) from the target. Error bars represent 99% confidence intervals.

Overall, the analyses suggest that the distance between the target and the singleton distracter did not significantly influence attentional capture effects in both Search groups.

Discussion

The current study aimed to understand if participants were more encouraged to utilise early cue information when searching for a difficult target. It was also questionable whether increasing the signal for the cued item would therefore reduce attentional capture for a task-irrelevant item displayed near or far from the target. It was expected that search for a conjunctive target would promote endogenous cue-utilisation and therefore influence attentional capture. The findings did show that participants who searched for a conjunctive target (i.e. tilted exclamation point) had larger cueing ratios than those who searched for a singleton target (i.e. tilted line) but this difference was only significant at the $p < .05$ level. In addition, attentional capture effects did not change as a function of search difficulty.

Rather, the distance between the target and the singleton distracter may have influenced attentional capture effects, but this effect was not shown to be significant. It should be noted that data collection for the current study is incomplete at the present moment. Thus, the findings which were close to significance will be discussed to understand the *direction* of the results, whilst taking into consideration that any possible conclusions drawn are cautious at this time and will be further reviewed once data collection has been completed.

Cue-Utilisation

This study examined whether search for a conjunctive target would encourage participants to use early cue information to facilitate performance. It was expected that, if this was the case, participants in the Difficult Search group would have larger cueing ratios in the Mostly Predictive block compared to the Baseline block, but more critically for this question, compared to the Easy Search group. The findings show that participants in both the Easy and Difficult Search groups had significantly larger cueing ratios in the Mostly Predictive block relative to the Baseline block. Critically however, participants in the Difficult Search group had larger cueing ratios in the Mostly Predictive than those in the Easy Search group but this effect only reached significance at the $p < .05$ level (Block x Search Group; $p = .013$). Therefore, this finding is indicative and is in line with the predictions and previous research which has shown conjunction search encourages endogenous cue-utilisation relative to feature search (Hannus et al., 2020; Henderickx et al., 2010; Kawahara & Miyatani, 2001; Sobel et al., 2009; Zhuang & Papathomas, 2011). It would extend these findings by suggesting that a conjunctive target could promote more endogenous cue-utilisation compared to a singleton target.

This result could show that providing early information concerning a difficult target, helps participants select the cued area and also assists with *featural binding*. As the conjunctive target is made up by a number of features which are shared by the non-target items, this usually would require participants to scrutinise each item to locate the object which includes both task-relevant features of the target (Hendrickx et al., 2010). In contrast to this, a singleton target can be located by searching for the discrepancy in the search-display using a pop-out search (Theeuwes et al., 2006). Thus, early cue-utilisation may be promoted when searching for a conjunctive target as this item facilitates selection for the target on most trials in the Mostly Predictive block and this could in turn help participants bind the features to accurately locate the target (Hannus et al., 2020; Liesefeld et al., 2018). Thus search for a difficult target may have promoted reliance on early cue information and so this may have strengthened the cue-signal in this task, relative to Easy Search. The direction of the current findings are in favour of this interpretation but this conclusion is cautious at the .01 alpha level and will be further reviewed.

Overall, the results indicate that Difficult Search for a conjunctive target promotes endogenous cue-utilisation compared to Easy Search for a singleton target. This finding will be further reviewed once data collection is complete.

Attentional Capture

The current chapter assessed whether attentional capture could be influenced by search difficulty. It was expected that enhancing the signal of the cued item in the Difficult Search group would lead to reduced attentional capture on valid trials in the Mostly Predictive block, relative to the Baseline block and the Easy Search group. The findings showed that attentional capture was not influenced by search difficulty and there were no interactions with Search Group which were close to significance. This suggests that even when endogenous cue-utilisation was enhanced, participants were unable to reduce distraction caused by a singleton distracter. With regard to the signal suppression hypothesis, a stronger cue signal was insufficient to inhibit the early “attend to me” signal created by the singleton distracter (Luck et al., 2021; Sawaki & Luck, 2010).

Some have argued that difficult search tasks increase attentional capture compared to easy search tasks (Barras & Kerzel, 2017). Research using a variant of the additional singleton paradigm, has shown that when the target and the non-target items were highly similar to one another (i.e. square target and diamond singleton distracter), participants were unable to suppress attentional capture, relative to when there was low target/non-target similarity (Barras & Kerzel, 2017). Indeed, this was replicated in a study which manipulated the appearance of the non-target items whereby attentional suppression (Pd) was not achieved when the non-target items were heterogenous (i.e. differently oriented lines; Feldmann-Wüstefeld & Schubö, 2013). This suggests that difficult search tasks encourage serial search for the target and inhibition of non-target items which share features with the target and therefore there is a greater likelihood of getting distracted.

The current study did not find increased attentional capture in the Difficult Search group compared to the Easy Search group. Thus, the presence of an early cue could explain the differences between the current study and previous research, as participants in both Search groups utilised cue information to guide their attention endogenously and this was shown even more so in the Difficult Search group. Although the cue did not influence capture at an early stage of processing, it may have assisted search at a later stage of processing after participants' attention was captured (Moher & Egeth, 2012; Moher et al., 2014). This replicates the interpretation from Chapter 6, whereby participants experienced less distraction on invalid trials in the Mostly Predictive block, compared to assigned trials in the Baseline block. This effect was also demonstrated in the current study and almost reached significance (Block x Cue Validity; p = .012). Participants' attention may have been captured, but then they avoided this item by reactivating the task-goal to search for the target in the cued colour (Moher & Egeth, 2012). Therefore, the assistance of the cue may have played a more dominant role at a late stage of processing to locate the item after being captured by the singleton distracter. This could explain how the cue assisted search in the

Difficult Search group, relative to previous studies which did not provide cue information and showed large attentional capture effects in this type of search task.

Distance Effects

By considering the distance between the target and the singleton distracter, this could provide some clarity over the dynamics of attentional selection once attention has been captured. It was predicted that when the target and the singleton distracter were near one another (</= 8.25cm) on valid trials, as opposed to further away, participants would either experience more attentional capture (Theeuwes, 2010) or less attentional capture (Tsotsos, 1995). The results showed distance effects on valid vs invalid trials did not reach significance (Cue Validity x Distance; p = .019). The direction of this effect suggests that when the target and singleton distracter were near one another, participants had smaller distraction ratios on valid trials, in comparison to when these items were further away from each other. This direction is in favour of the spatial surround suppression hypothesis, which proposes that engagement to a task-relevant item leads to inhibition of task-irrelevant signals which are close to the zone of focal attention (Tsotsos, 1995; Wong-Kee-You et al., 2019). In addition, research has shown that participants were able to suppress a singleton distracter which was near or within the window of attentional focus, as demonstrated by larger distracter-Pd responses and larger target-N2pc responses (Kerzel, Barras & Grubert, 2018). Thus, it could be that when participants were cued to the target on valid trials, their engagement on this task-relevant item ensured a close singleton distracter, which was irrelevant to the task-goal, was reduced.

In contrast to this, participants had large distraction ratios on invalid trials for near distances which could be suggestive of an *inhibition of return* effect. Invalid trials cued attention to a non-target item and so participants may have serially searched for the target by examining each item in small clusters (Belopolsky et al., 2007) or searched for the target more broadly by encompassing their search across the entire search-display and thus, were guided towards the most salient item in their visual field in a bottom-up fashion (Liesefeld et al., 2017; Theeuwes, 2010). In both cases, the direction of the findings suggest that participants experienced more attentional capture for near distances on invalid trials which could point towards an inhibition of return effect. This would suggest that after attention was captured by the singleton distracter, participants inhibited its associated location (which was close to the target) and searched elsewhere for the target item which enhanced their response times on these trials. This line of reasoning also agrees with Moher and Egeth's (2012) "capture, but then avoid" conclusion whereby once participants experience attentional capture they avoid this item and search for the target in task-relevant locations (i.e. coloured circles). The current study's findings could add that the avoidance strategy may be dependent on the location of the singleton distracter in relation to the target, as closer distances may unintentionally lead to inhibition of the target location and therefore be costly for locating this item.

In general, the findings suggest that search difficulty did not influence attentional capture. Critically, enhanced cue-use in the Difficult Search group did not reduce capture effects. At the same time, capture effects were not enlarged in Difficult Search as predicted by previous evidence (Barras & Kerzel, 2017; Feldmann-Wüstefeld & Schubö, 2013). This could suggest that the presence of the cue may have helped participants to reactivate their task-goal to search for the cued colour after attention was captured, at a late stage of processing (Moher & Egeth, 2012). In addition, attentional capture may be influenced by the distance between the target and the singleton distracter. It is possible that focal engagement on the validly cued target could assist with surround inhibition when the singleton distracter is near, but greater capture or inhibition of return on invalid trials for near distances. The findings for distance effects were interpreted on the basis of their direction as the interaction was close but did not meet significance and therefore this conclusion is cautious.

Limitations

As previously mentioned, data collection for the current study has been paused at this present time and so the findings may be underpowered. A number of the findings discussed above were close or equal to the significance level which made interpretation difficult and conclusions cautious. The choice to keep my significance level conservative at .01 was due to my decision to 1) reduce the likelihood of false positive results and 2) to remain open and in line with my pre-registration for my analyses in this study and my previous studies. There is much debate regarding whether significance testing should be universally used to test the null hypothesis (Benjamin et al., 2018; Lakens et al., 2018; Trafimow et al., 2018). One key suggestion from this debate is that p-values close to .05 make it difficult to produce strong conclusions against the null hypothesis (Lakens et al., 2018). Indeed, Benjamin et al. (2018) found that an alpha of .05 can lead to a higher likelihood of finding a false positive which in turn affects the replicability of those results. I therefore used a conservative approach by using an alpha of .01 and maintained this criterion in the pre-registration on the Open Science Framework. By making my predictions and planning the analysis at an early stage in data collection, this ensured that I was unbiased and prevented p-hacking (Benjamin et al., 2018). Therefore, I maintained the alpha criterion of .01 despite the data collection being only partially complete and hope to re-analyse the data using a full dataset once it is safe to do so.

The target item used in the Easy Search group and the Difficult Search group was not kept constant, which could have influenced comparisons made between these groups. To strengthen comparisons between search tasks, it is recommended that the target item remains the same but the non-target items differ (Bacon & Egeth, 1994; Gaspelin et al., 2015, 2017). This ensures that the search difficulty is operationalised by manipulating the relationship between the target and non-target items between Search groups, rather than the target itself. It is possible that searching for a solid tilted line is easier compared to searching for a gapped tilted exclamation point, irrespective of its similarity to the non-targets. Therefore, this factor in addition to the target's similarity to the non-target items could have contributed towards search difficulty between the groups. If search for a solid line is easier than a gapped line, then this factor would be congruent with the Search group manipulation and may not have played a large role in influencing the direction of the findings. Future studies with this task should aim to use the same target and only manipulate its relationship to the non-target items to clearly define and manipulate search difficulty.

Future Directions

One possible line of reasoning for the reduced role of valid cue-utilisation on attentional capture in the Difficult Search group could be due to perceptual load. Evidence has shown that high perceptual loads can reduce distraction, relative to low perceptual loads, as less cognitive capacities are available to spill over to task-irrelevant items (Forster & Lavie, 2008; Lavie, 1995). Perceptual load can be manipulated in a number of ways, including search type (easy vs difficult) and set size (small vs large; Lavie, 2010). Some evidence has shown that high perceptual loads induced by difficult search, cannot reduce capture effects in adults (Chen & Cave, 2016; Lleras, Chu & Buetti, 2017). However, others have shown that increasing the set size can modulate capture effects (Cosman & Vecera, 2010a, 2010b). It is possible that, as the set size was fixed, perceptual load may have been low and within capacity for young adults (Cosman & Vecera, 2010a; Matusz et al., 2015). Future research with the current paradigm should aim to consider the influence of differential set sizes on easy vs difficult search to understand its influence on modulating attentional capture.

Conclusion

The present study investigated whether difficult search for a conjunctive target influenced cue-utilisation and attentional capture effects.

The findings show that participants in the Difficult Search group utilised endogenous cues to facilitate search more than those in the Easy Search group. This suggests that when search is difficult, early cue information can help participants to prioritise and select the target item on most trials and this could have assisted featural binding of the conjunctive target to locate it. Contrary to predictions, search difficulty did not influence attentional capture; suggesting that even when the endogenous cue-signal is strengthened in Difficult Search, this early information is insufficient for avoiding capture. The results highlight a potential link between attentional capture and distance effects between the target and the singleton distracter which warrant further consideration.

Chapter 8: General Discussion

Abstract

The final chapter considers the research findings from the thesis as a whole to gain a deeper understanding of endogenous cue-utilisation and attentional capture across the lifespan. I first reflect on and summarise the research findings from each chapter before delving into an in-depth discussion. I explore what the research findings tell us in relation to my thesis aims. By using a developmental approach, I expand the definition of endogenous cue-utilisation to entail 1) the use of context to create and maintain task-goals, 2) domain-specificity and 3) independence from inhibitory processes with increasing age. The influence of endogenous cues on attentional capture suggest cues are unable to override capture at an early stage of processing but may be able to modulate the effect of capture at a late stage of processing. The research findings are related to past research to demonstrate the gaps addressed in the literature. Future research should aim to consider the role of long-term task-goals and selection history on the adaptive use of endogenous cue-utilisation.

Summary of findings

Chapter 2:

- Using the additional singleton paradigm, adults were significantly slower by 41ms at responding to the target when the shape singleton distracter (i.e. a black diamond amongst colourful circles) was present in the search-display vs when it was absent; suggestive of a moderate attentional capture effect.
- The location of the singleton distracter with reference to the location of the target influenced responses. When the singleton distracter was in the same quadrant as the target, relative to a different quadrant, this improved accuracy for discriminating the tilt of the target but it did not influence response times.

Chapter 3:

- Endogenous cue-utilisation is still developing in five- to six-year-olds but becomes adult-like by nine- to 11 years old: Both adults and nine- to 11-year-olds had larger cueing ratios in the Mostly Predictive block compared to the Low Predictive (33.33% valid cues) and Baseline (100% neutral cues) blocks. In contrast, cueing ratios did not significantly differ across all block conditions in five- to six-year-olds.
- Endogenous cues in the Mostly Predictive block were insufficient for reducing distraction in children & adults.
- Better maintenance of the cue in the Mostly Predictive block predicted poorer inhibition of the singleton distracter in the Baseline block in five- to six-year-olds.
- No trade-off was found between maintenance and inhibition in nine- to 11-year-olds and adults.

Chapter 4:

- Abnormalities in assigned “valid” and “invalid” trials of the Baseline block of Chapter 3 were considered, as participants had a positive correlation between “cueing” ratios and distraction ratios within this condition. There was also more distraction on invalid trials compared to valid trials, which could have been driven by assigned trials in the Baseline block.
- Cross-colour priming effects (e.g. blue cue primes attention to target in green) were considered and whether more of these trials were assigned as “valid” vs “invalid” in the Baseline block. The findings opposed this prediction and suggested that participants tended to have a preference at responding faster to targets presented in blue and pink circles, which were counterbalanced across all trials and block conditions.

Chapter 5:

- The influence of block predictiveness on cue-utilisation was considered without the presence of the singleton distracter. Both five- to six-year-olds and nine- to 11-year-olds utilised the cues to guide their attention when the cue was Mostly Predictive (66.67% valid) and Always Predictive (100% valid) of the target, compared to Baseline (100% neutral).

- No age differences were found in cue-utilisation; both age-groups were able to sustain cue use in the Mostly Predictive block, compared to the Baseline block.

Chapter 6:

- Endogenous cue-utilisation in the Cued Visual Search task and the AX-CPT was compared in young and older adulthood. Older adults utilised cues endogenously as effectively (Cued Visual Search) or less effectively (AX-CPT) as young adults.
- Endogenous cue-use in the AX-CPT did not predict cue-use in the Cued Visual Search task and this relationship did not change with age.
- Young and older adults experienced less distraction on invalid trials in the Mostly Predictive block, compared to Baseline; suggestive of a “capture, but then avoid” effect (Moher & Egeth, 2012).

Chapter 7:

- The influence of search difficulty for finding the target was considered. The findings indicated that cue-use was greater when search was difficult (i.e. conjunctive target) compared to easy (i.e. singleton target).
- Despite increased cue-use in difficult search, participants were unable to reduce attentional capture using valid cues. The *direction* of the results suggest that reduced distraction on invalid trials was replicated from Chapter 6.
- Attentional capture may have been influenced by the distance between the target and the singleton distracter, as the findings indicated reduced distraction on valid trials for near distances vs invalid trials.

The current chapter will discuss the summarised findings in relation to the aims of the thesis highlighted in Chapter 1:

1. **Endogenous Cue-Utilisation** – I will discuss this higher-order skill and the conditions required to encourage this form of control whilst considering its development from its early form in five- to six-year-olds, its adult-like form in nine- to 11-year-olds and its matured form in seniority.
2. **Attentional Capture –** I will highlight whether endogenous cue-utilisation can overcome capture by a singleton distracter across the lifespan, with links to previous research findings.
3. **Maintenance & Inhibition Relationship** – By comparing cue maintenance and inhibition of a singleton distracter, this can emphasise the dynamic between these distinctive processes and its influence on performance across age. The findings for this aim will be considered in my discussion of attentional capture.

The findings will be discussed with reference to each of the thesis aims as well as consider the abnormalities found in the Baseline block. The results from this thesis will be related to the gaps in the literature it has addressed. Relevant limitations and future directions will be mentioned during this discussion, but will later be conversed in depth in its relevant section before making a concluding statement.

Endogenous Cue-Utilisation

Endogenous control is often understood as a volitional skill which allows users to maintain an early task-goal to bias their attention towards task-relevant items in their environment (Soto et al., 2008). Visual working memory is often cited as playing a significant role in the assignment of attentional weights on task-relevant items as it has a limited capacity which can bias attentional resources towards a memory matching item (Cowan, 2010; Desimone & Duncan, 1995). But the complexity of this skill suggests that there may be more at play. The findings from the current thesis have highlighted the influence of age, context, the possible role of a singleton distracter on cue-use (Chapters 3 & 5), task demands (Chapter 6) and the influence of search difficulty for a complex target (Chapter 7). In combination, the findings emphasise the complexities of this higher-order skill in relation to its development across the lifespan. I will discuss the development of endogenous cue-utilisation to allow us to gain a greater understanding of the limits of this skill in setting and maintaining a task-goal from an early age to seniority.

The findings from this thesis questioned the age at which children can acquire a task-goal through contextual information. Research has suggested that the production of an early task-goal is required to assign attentional weights to task-relevant items in our visual field, in order to bias attention towards these items and reduce the chance of attention being engaged by task-irrelevant items (Treisman & Sato, 1990; Wolfe et al., 1989, Wolfe, 2014). By manipulating block predictiveness, this aimed to encourage participants to learn about the relevance of the cue for guiding attention towards the target. In addition, by acknowledging the task-goal during the practice phases (i.e. *were the clues helpful*), this also helped participants to create the task-goal. Thus, maintenance of this task-goal was expected to encourage participants to engage the cues which in turn could adjust the attentional weights for the target feature on a trial-by-trial basis (Kiyonaga et al., 2012; Leclercq & Siéroff, 2013; Woodman et al., 2013). Next I will discuss my findings concerning the development of endogenous cue-utilisation in children.

Early- to Mid-Childhood

The ability to use contextual information to create an early task-goal has developed from an early age and stays relatively constant throughout childhood. The findings in Chapter 5 showed that children as young as five, were able to use contextual information to encourage them to differentially maintain the cues to guide attention. Indeed, no age differences were found between five- to six-year-olds and nine- to 11-year-olds for engaging endogenous control in Cued Visual Search, when only block predictiveness was manipulated. As both groups were able to benefit the most from Always Predictive (100% valid) cues, as well as engaged in endogenous cue-use when block predictiveness was not maximal in the Mostly Predictive block (66.67% valid; at $p < .05$ level), relative to Baseline (100% neutral). This supports research which suggests that endogenous cue-utilisation stays relatively stable from ages five to 11 (Hermens, 2018; Johnson et al., 2020; Lewis et al., 2016) in a manual discrimination task; opposing the view that this effect is only shown in saccadic eye-movements (Landry et al., 2019). Thus, the ability to use context to create an endogenous task-goal appears to have developed from a young age but this finding will be reviewed once data collection is complete.

From ages five to six, my results also suggest that endogenous cue-utilisation has developed but young children may be limited to using this skill in situations of low distractibility. In Chapter 3 when a singleton distracter was present on some of the trials, five- to six-year-olds showed non-significant differences in cueing ratios across block conditions. Individual differences showed that those who were better at maintaining the cue were poorer at inhibiting the singleton distracter when these skills were measured independently. This is suggestive of a cognitive trade-off between these two skills at a young age. In contrast to this, Chapter 5 did not include a singleton distracter and found five- to six-year-olds were able to maintain cues endogenously to guide attention as effectively as nine- to 11-year-olds in the Mostly Predictive and Always Predictive block conditions. This suggests that even when block predictiveness was not at its maximum, young children were still encouraged to maintain the mostly predictive cues and sustain this across the block condition. The contrast in the results for this age-group in Chapters 3 and 5 highlight that the presence of the singleton distracter may limit whether five- to six-year-olds, but not nine- to 11-year-olds, can successfully use endogenous control.

It is possible that the presence of a singleton distracter can influence endogenous cue-utilisation at an early age in development. Endogenous cue-utilisation is often regarded as a biasing of attention towards items maintained in visual working memory (Carlisle et al., 2011; Kiyonaga et al., 2012; Soto et al., 2005, 2008). Individuals who exert less control over the updating or filtering of maintained items in this store may be more likely to increase the cognitive load of the task (Cowan, 2010; Fukuda & Vogel, 2009; Lavie et al., 2004). Evidence has shown that adults with low visual working memory capacities were worse at filtering task-irrelevant items from their working memory store for the next trial, as suggested by their enhanced contralateral delay activity relative to high-capacity adults (Fukuda & Vogel, 2011; Vogel et al., 2005). This suggests that low-capacity individuals may also have less control over filtering task-irrelevant items to make room for task-relevant items (Cowan, 2010, 2011), which may unintentionally increase the cognitive load of the task; making it more difficult to maintain early cues in this store to guide attention (Soto & Humphreys, 2009).

Thus, the current findings could correspond with research which has suggested that young children have less control over maintained items in working memory (Cowan, 2010). Between ages five and six, children undergo a number of key transitions in executive function and attentional control (Diamond, 2013; Munakata et al., 2012). Evidence has shown that working memory capacities begin to increase during this period (Carlson, 2005), which has been related to their structural development at the cortical level (Kharitinova et al., 2005, 2009). Indeed, children as young as seven showed similar working memory performance to adults for recalling a cued item in a visual array (Cowan, Morey, AuBuchon, Zwilling & Gilchrist, 2010). However, when the cognitive load of the task was increased, seven-year-olds were less effective at filtering out task-irrelevant items from working memory, relative to 12-year-olds. This is also shown in five- to six-year-olds, as individuals who were better at switching between task-goals also experienced greater distraction in a delayed match-to-sample task than non-switchers (Blackwell et al., 2014; Blackwell & Munakata, 2014). Thus the current findings could suggest that five- to six-year-olds may have less control over filtering the singleton distracter from working memory, compared to nine- to 11-year-olds, which may have increased the cognitive load of the task. In addition, as they also have smaller cognitive capacities than nine- to 11-year-olds and adults (Diamond, 2013), they may therefore have less attentional resources available to maintain the task-relevant cues. This claim warrants further investigation to gain a clearer depiction of the limits for endogenous cue-use in young children (*see Limitations & Future Directions*).

Later in childhood, the findings from Chapters 3 and 5 suggest an adult-like endogenous form of control has been acquired. Children aged nine to 11 utilised endogenous control in both studies irrespective of the singleton distracter. In Chapter 3, like adults, they had larger cueing ratios in the Mostly Predictive block compared to the Low Predictive (33.33% valid cues) and Baseline block conditions. This corresponds with past research which has shown 10-year-olds to behave similarly to adults in orienting their attention endogenously (Goldberg et al., 2001; Leclercq & Siéroff, 2013; Pearson & Lane, 1990; Shimi et al., 2014; Wainwright & Bryson, 2005). This is also in line with neural research which has shown successful use of endogenous orienting to be supported by areas in the fronto-parietal network, which are also activated by adults but in less time and less effortfully (Hämmerer et al., 2010; Shimi et al., 2015). Therefore, this research supports the view that an adult-like form of endogenous control has been acquired before adolescence. Next, I discuss my results on endogenous cue-utilisation in older adulthood before summarising the findings on this theme in the thesis.

Older Adulthood

My aims concerning age-related changes in endogenous control in older adulthood were assessed using two measures of this skill. By comparing performance in Cued Visual Search and the AX-CPT, this highlighted 1) the disparities in endogenous control in older adults and 2) the domain-specificity of this skill. I will consider both points with reference to our current theories of attentional selection.

My research findings suggest that endogenous cue-utilisation is preserved in older adulthood. In Chapter 6, the Cued Visual Search task showed age-equivalency in cue-utilisation performance in the Mostly Predictive block, relative to the Baseline block. In addition, both age-groups used endogenous (or proactive) control in the AX-CPT, but cue-use was significantly less in the older adults relative to the young adults. These findings oppose the view that endogenous control declines into the main use of exogenous (or reactive) control in older adulthood (Braver et al., 2005, 2009; Paxton et al., 2008). Rather, endogenous cue-utilisation for guiding attention is as effective (Cued Visual Search) or slightly less effective (AX-CPT) as the form of control acquired by young adults when measured at the behavioural level (Greenwood & Parasuraman, 2004; Kray et al., 2015). This evidence is consistent with neural findings, which have shown similar performance at the behavioural level but greater bilateral activity, as opposed to unilateral activity, in the fronto-parietal regions in older adults (Hammerer et al., 2010; Huang et al., 2012). Hence, the research findings could be suggestive of a compensatory mechanism for frontal atrophy in older adults (Cabeza, 2002; Huang et al., 2012), whereby endogenous performance at the behavioural level could be a consequence of effortful processing at the neural level.

Endogenous control may be domain-specific and dependent on the task demands in the measurement of this skill. Chapter 6 showed that cue-utilisation in the AX-CPT did not significantly predict cue-utilisation in the Cued Visual Search task and this relationship was not moderated by age. This suggests that individuals who had good cue-use in the AX-CPT did not necessarily have good cue-use in the Cued Visual Search task; an effect which did not change with increasing age. This could explain older adults' differences in performance in the AX-CPT (worse than young adults) and the Cued Visual Search task (no different to young adults). If endogenous cue-utilisation activates different underlying mechanisms in both of these measures, this could provide greater clarity for our definition and measurement of this higher-order skill.

By comparing Cued Visual Search and AX-CPT performance, the findings could suggest that older adults do not have a task-goal maintenance *deficit* per se (Braver et al., 2001) but rather they may have difficulty with long-term representations of the task-goal compared to young adults. In Cued Visual Search, participants learn that when they see the cue this will inform them of the upcoming target’s feature which changes on a trial-by-trial basis. In the AX-CPT, participants learn that when they see the cue “A” (i.e. hen) they will see probe “X” (i.e. cat). It could be argued that the Cued Visual Search task requires more active adjustment of the attentional weights to the cued feature which changes on a trial-by-trial basis, relative to the AX-CPT (Bundesen, Habekost & Kyllingsbaek, 2005). Research has argued that a target or cue which changes on a trial-by-trial basis makes it more difficult to retain a high level task-goal in long-term memory to bias attention but rather relies on flexible adjustment of attentional weights using visual working memory (Woodman et al., 2013). Evidence has shown that when the cued feature of the target changes on every trial, visual working memory (i.e. contralateral delay activity) is enhanced but the involvement of this function is reduced when the cued feature of the target is constant across several consecutive trials (Carlisle, Arita, Pardo & Woodman, 2011; Gunseli, Olivers & Meeter, 2014). In contrast, the increase in long-term representation signals (P170) are enhanced (Carlisle et al., 2011). This suggests that with experience for a constant feature, the reliance on visual working memory is reduced and the long-term representation of this feature is relied on more to bias attention (Vecera, Cosman, Vatterott & Roper, 2014; Woodman et al., 2013). Thus, older adults may be as effective as young adults at using visual working memory to guide attention in Cued Visual Search, but their ability to maintain and retrieve long-term representations to bias attention may be less robust.

From this discussion, the development of endogenous cue-utilisation has highlighted a number of factors which define this skill. First, the ability to use contextual information to produce differential task-goals has developed by early-childhood (5-6 years) and stays relatively stable through to mid-childhood (9-11 years). Second, immature forms of endogenous cue-utilisation may be limited by a cognitive trade-off with inhibitory skills, whereby the ability to maintain information may be dependent on the level of control over visual working memory in filtering irrelevant distractions. Third, an adult-like form of endogenous control has developed by mid-childhood and is retained in older adulthood, contrary to predictions. Lastly, by considering the use of this higher-order skill in different measures, it is possible that endogenous control is task-dependent and may be used differently when attentional weights for task-relevant features are adjusted flexibly on a trial-by-trial basis. Next, I will discuss whether endogenous cue-utilisation can overcome attentional capture in children and adults.

Attentional Capture

In this section, I will focus my discussion on the relevant theories of attentional capture to understand the limits of endogenous cue-utilisation for reducing distraction. Critically, the findings suggest that endogenous cues are insufficient for reducing or preventing attentional capture at an early point in processing. This effect was shown in both children and adults, which suggests that it did not vary with age. It has been argued that fixed or long-term task-goals are sufficient to override attentional capture (Gaspelin et al., 2015, 2017; Wang & Theeuwes, 2018). I will consider the dynamics of top-down and bottom-up processes during attentional selection and make relevant comparisons with previous research to gain a clearer depiction of the influence of endogenous cues on attentional capture.

The research findings show that endogenous cues did not influence attentional capture at an early point in processing. It was expected that participants would have the most incentive to use valid cues in the Mostly Predictive block to reduce attentional capture to the singleton distracter. This is because hybrid attentional selection accounts suggest maintenance of an early task-goal can increase the attentional weight given to task-relevant or cued features to bias attention towards this feature and disregard task-irrelevant features (Bundesen et al., 2005; Sawaki & Luck, 2010; Treisman & Sato, 1990; Wolfe, 2014). Contrary to predictions, children and, more surprisingly, adults were unable to reduce distraction on valid trials (Chapter 3). This was replicated even when provided with more time to encode and build anticipation for the cued feature (Chapter 6), as well as when the cue signal was increased when the target was more difficult to locate (Chapter 7).

Thus, the evidence from this thesis provides a caveat to hybrid accounts of attentional selection, in showing that early endogenous cues are unable to overcome attentional capture, even under conditions which are known to enhance cue-maintenance (Berger et al., 2005; Hannus et al., 2020).

One possible explanation for this result could be that the nature of endogenous cues which change on a trial-by-trial basis may limit long-term effects of the task-goal on biasing attention. As discussed in the previous section, long-term representations of the task-goal can bias attention when the goal is consistent and reduces the reliance on visual working memory (Vecera et al., 2014; Woodman et al., 2013). Previous research has replicated the prevention of attentional capture with a consistent task-goal, when participants were encouraged to always search for the same target item (Gaspar et al., 2016; Gaspar & McDonald, 2014; Gaspelin et al., 2015, 2017; Jannati et al., 2013) or learn that the singleton distracter would most likely be presented at a certain location (Wang & Theeuwes, 2018; Wang et al., 2019). It could be argued that these manipulations ensured that the task-goal was a long-term goal and so participants may have relied on visual working memory less to adapt the attentional weights to task-relevant features. In Cued Visual Search, the task-relevant feature (i.e. the target line's surrounding colour) changes frequently and so flexible control is required to utilise the cues to bias attention to different feature values (Bundesen et al., 2005; Woodman et al., 2013). Indeed, the revision of the signal suppression hypothesis posits that the changing dynamics of a task-relevant feature could influence *stimulus history* and thus require participants to adapt the task-goal. This may make participants more likely to utilise an exogenous or reactive form of control at a late stage of processing (Luck et al., 2021). Therefore, endogenous cues in the current thesis as well as previous research (Beck et al., 2018; Moher & Egeth, 2012; Moher et al., 2014; Noonan et al., 2016), may have been unable to reduce or prevent attentional capture due to the adaptive nature of the task which reduces the involvement of long-term task-goals in biasing attention at an early stage of processing.

In support of this, the current thesis may have shown that endogenous cues influenced attentional capture at a late stage of processing. The findings from Chapters 6 and 7 suggested that young and older adults had smaller distraction ratios on invalid trials in the Mostly Predictive block compared to assigned "invalid" trials in the Baseline block, which shared the same search-display (at $p < .05$ level). This evidence could suggest that once attention was captured by the singleton distracter on invalid trials, adults may have modulated this effect by reactivating the task-goal in search for the target (Iarocci et al., 2009; Luck et al., 2021). This is commonly referred to as a "capture, but then avoid" effect whereby participants recover from capture by utilising the task-goal at a late stage of processing to minimise further distraction and favour attention towards task-relevant items (i.e. the coloured circles) in search for the target (Beck et al., 2018; Moher & Egeth, 2012; Moher et al., 2014). This is also supported by the attentional window hypothesis which has shown that top-down processes can set the size of the attentional window at a late stage of processing (Belopolsky et al., 2007; Theeuwes, 2010). Therefore, participants may have rapidly disengaged their attention from the singleton distracter and then avoided this item by reactivating the task-goal at a late stage of processing, which facilitated recovery from distraction in favour of the target.

It is uncertain however whether attention was first engaged to the cued item before being captured by the singleton distracter. The findings from Chapter 2 suggest that attention is engaged by the most salient item in the search-display, as when the target and the singleton distracter were within the same locus of attention (i.e. the same quadrant), accuracy for responding to the target line was improved (Liesefeld et al., 2017; Tsotsos, 1995; Wong-Kee-You et al., 2019). Thus the attentional window to locate the target may encompass the whole search-display and so attention is guided based on saliency computations in a bottom-up fashion (Theeuwes, 2010; Van der Stigchel et al., 2009). That being said, if attention was engaged by the most salient item in the array first, then one would expect no differences in attentional capture effects for valid vs invalid trials. Although a non-significant effect of distance on cue validity was found at the *p* < .01 level, the direction of the findings from Chapter 7 could indicate that participants experienced reduced levels of distraction on valid trials vs invalid trials for near target/distracter distances. This could suggest that when attention was validly cued towards the target, participants may have reduced engagement to items (i.e. the singleton distracter) surrounding the focal zone of attention (i.e. the target; Barras & Kerzel, 2017; Tsostos, 1995). In contrast, when attention was invalidly cued towards a non-target item, an inhibition of return effect may have occurred whereby attention was captured by the singleton distracter, inhibited and then avoided by searching elsewhere for the target; increasing response times on singleton-present trials (Moher & Egeth, 2012). Therefore, the influence of distance on the findings could indicate that participants engaged their attention on the cued item first before attention was captured by the singleton distracter. However, the results were not significant at the *p* < .01 level and so this conclusion is cautious and will be further reviewed (*see Limitations & Future Directions*).

From the discussion, the current thesis has shown that endogenous cues which assisted search for the target are unable to reduce or prevent attentional capture from a singleton distracter. This could be due to the adaptive nature of the cues which could be argued to require visual working memory to adaptively adjust the attentional weights to task-relevant features. This may make it difficult to encompass a long-term representation of the task-goal to bias attention (Vecera et al., 2014; Woodman et al., 2013). Thus, reactivation of the cued feature at a late stage of processing may facilitate performance by modulating the effect of capture (Beck et al., 2018; Iarocci et al., 2009; Luck et al., 2021; Moher & Egeth, 2012; Moher et al., 2014). Next, I will discuss the relationship between maintenance and inhibition skills in Cued Visual Search to understand the changing dynamics between these skills across development.

Maintenance & Inhibition Relationship

The ability to maintain early information, such as a cue, has been shown to facilitate attention. To recover from attentional capture, one must inhibit this item to disengage and redirect attention elsewhere in search for the target. I investigated the predictive relationship between these skills when measured independently in the Cued Visual Search task, to understand whether they influence one another. I defined maintenance as cueing ratios in the Mostly Predictive block on singleton-absent trials. Inhibition was defined as distraction ratios in the Baseline block where there was little to no effect of the cue. Research has suggested that maintenance and inhibition abilities are independent processes. Evidence has shown that the ability to maintain a cued feature of a distracter and the ability to inhibit this item were not related to one another in young adults (Noonan et al., 2016). The current findings from Chapter 3 and 6 extend this claim by showing that maintenance and inhibition abilities in the Cued Visual Search task become independent processes once an adult-like endogenous form of control has developed (9-11 years) and this distinction remains in seniority (60-84 years). However, at an early age of development there is a cognitive trade-off between these skills whereby individuals who were better at maintaining the cue were poorer at inhibiting a singleton distracter. This result suggests that the dependence between these processes changes with age.

Many have suggested that maintenance of a feature enhances activation for this task-relevant feature but also has an inhibitory effect on task-irrelevant features (Beck et al., 2018; Moher & Egeth, 2012; Treisman & Sato, 1990). My findings suggest that individual differences in maintenance ability does not predict variation in the inhibition of a task- irrelevant item. Thus enhancing the signal for the target may increase the attentional weight for saliency computations for the target but play less of a role in down-regulating task-irrelevant features. Indeed in ERP, cue-related maintenance (P3) and distracter-related suppression (Pd) are measured as distinctive processes in the fronto-parietal regions (Gaspelin et al., 2015, 2017; Hickey et al., 2009) and thus, these skills are critical to enable attentional guidance and inhibitory recovery but are distinguishable from one another.

At a young age, encouraging maintenance of early information may come at a cognitive cost. It is often thought that promoting endogenous (or proactive) engagement during the younger years would benefit performance in everyday tasks (Chevalier et al., 2015; Kubota et al., 2020). An alternative school of thought argues that encouraging this demanding skill on early attentional processes in young children may incur a cost on cognitive performance (Blackwell & Munakata, 2014). The current findings support the latter as they suggest that individuals aged five to six who have good maintenance abilities, may have poorer inhibition abilities. Therefore, those who have developed immature forms of endogenous control may experience a cost or cognitive trade-off between maintenance and inhibition skills in situations of high distractibility. It is important to note that the findings from my studies were based on comparisons between Mostly Predictive and Baseline blocks, however there were some unexpected patterns of behaviour within the Baseline block. I will next delve into an in-depth discussion to address the variability found in this condition before considering the gaps in the literature addressed by this thesis.

Baseline Block

The Baseline block aimed to provide irrelevant information concerning the target’s upcoming feature to ensure attention was neither guided towards or away from the target. The *Hillyard Principle* states that sensory confounds can be reduced by ensuring the physical stimuli between comparison measures are kept constant but only the psychological manipulations are different (Hillyard, Hink, Schwent & Picton, 1973; Hillyard & Münte, 1984; Sawaki & Luck, 2014). To compare performance in the Mostly Predictive block to the Baseline block whilst being mindful of the Hillyard Principle, trials in the Baseline block were assigned “valid” and “invalid” labels to match the Mostly Predictive block. This ensured that the elements in the search-display were kept constant on these trials between block conditions, but it was only the colour of the cue which was manipulated. This strengthens my comparisons by showing that when the cue colour matches the colour of an item in the search-display of the Mostly Predictive block, this cue differentially influenced attentional guidance compared to a cue colour that was absent from the search-display in the Baseline block.

However, a sensory confound may still remain in the Baseline block as an abnormality was found between assigned trials in this condition. In Chapter 3, a positive correlation was found between cueing ratios and distraction ratios within the Baseline block, suggesting that greater "cue-use" in this condition was related to increased levels of attentional capture. Indeed, in Chapter 3 a main effect of Cue Validity suggested distraction ratios were smaller on valid vs invalid trials (*p* = .046) but this may have been driven by assigned trials in the Baseline block. This was confirmed in Chapter 6 (and Chapter 7; *p* = .012) which replicated this effect specifically in the Baseline block. In addition, Chapter 6 showed cueing ratios in the Baseline block were below 1 in both young and older adults which may be suggestive of faster response times on assigned "invalid" trials relative to "valid" trials in this block condition. During my thesis, I considered whether there were 1) cross-colour priming effects and 2) distance effects specific to the Baseline block. I will discuss the findings and conclusions for each of these points.

I investigated whether cross-colour priming effects were present and related to my variable assignment in the Baseline block. Cross-colour priming is thought to result from selective tuning for colours which have similar but not exact physical properties to a categorically different colour (e.g. blue primes target in green; Liu, 2019; Martinovic et al., 2018). In Chapter 4 I analysed singleton-absent trials using data from Chapter 3, to assess whether there were more trials assigned to "valid" vs "invalid" which produced cross-colour priming. However, this prediction was rejected as the results showed that participants had a general preference to respond faster to targets presented in blue and pink circles. In addition, Chapter 6 showed that individual differences in cross-colour discrimination did not significantly predict 1) cueing ratios in the Mostly Predictive block and 2) were weakly related to distraction ratios in the Baseline block (*however, see Limitations*). The findings therefore suggest that the abnormalities seen in the Baseline block have less to do with the influence of the cue in this condition. To further reflect on this, one would expect a prime which does not match the target colour to have little influence on attentional capture, as a cue which exactly matched the target colour was shown to have no influence on capture effects. Therefore, this suggests that the abnormalities in the Baseline block may be related to the singleton distracter.

The distance between the target and the singleton distracter is known to influence attentional capture and so I considered whether this affected performance in the Baseline block in Chapter 7. I assessed this because my experiment randomly selected a location within a prespecified quadrant for all elements within the search-display and so there was some level of variability in target/distracter distances in matched trials in the Mostly Predictive vs Baseline blocks. The *direction* of the results from Chapter 7 indicated that the distance between these items may have differentially influenced valid relative to invalid trials, but this effect was not specific to the Baseline block as it also occurred in the Mostly Predictive block. One could question why distance effects could be different on assigned “valid” and “invalid” trials as the cue could not inform participants of the colour of the upcoming target. However, the finding from Chapter 7 was non-significant at $p < .01$ level and is based on an incomplete dataset and so further consideration of this effect will need to be reviewed.

From my assessment and knowledge of sensory confounds in the Baseline block, I now question whether this condition was subject to intertrial effects. Research has shown that repetitions of the target (Sawaki & Luck, 2010), the cued feature (Carlisle et al., 2011; Theeuwes & van der Burg, 2011) and the location of the singleton distracter (Wang & Theeuwes, 2018) in consecutive trials, can lead to faster response times compared to non-consecutive trials. Intertrial effects have also been shown to reduce attentional capture effects (Theeuwes & van der Burg, 2011) but this is heavily debated (Ásgeirsson & Kristjánsson, 2019). I counterbalanced the elements in my task to control for learned associations at the block level, however the order in which the trials were presented was selected randomly and differed between block conditions. There is reason to question the presence of more intertrial effects in assigned “valid” trials vs “invalid” trials in the Baseline block but I would also expect similar effects in the Mostly Predictive block, unless a cue differentially influences this effect. In addition, it is difficult to disentangle intertrial effects without purposefully manipulating this factor as the behavioural profile of faster vs slower response times can apply to target, cue and singleton distracter repetition effects. Therefore, a future direction for this research is to manipulate intertrial effects to further understand the Baseline block.

In general, the variation within the Baseline block has been considered and reflected on in this thesis. This type of variability is not uncommon in Cued Visual Search and especially in attentional capture research. Others tend to a use a dual approach of methods (i.e. ERP/behavioural or eye tracking/behavioural) to disentangle variability effects within their tasks (Gaspar & McDonald, 2014; Jannati et al., 2013; Liesefeld et al., 2017; Sawaki & Luck, 2010, 2014). I have shown that cross-colour priming and distance effects played a reduced role in explaining the effects specific to the Baseline block. I propose that the possibility of intertrial effects in this condition warrants further investigation. Nevertheless, it is important to reiterate that the behaviour in the Baseline block is representative of participants’ performance when they are not provided with an informative cue. Thus, comparisons between performance in the Mostly Predictive block, where the cue guides attention, and the Baseline block hold merit in informing us about endogenous cue-guidance. Next I will discuss the gaps in the literature which have been considered by the findings in this thesis.

Gaps in Literature Addressed by This Thesis

A number of uncertainties in the attentional control and attentional capture literature have been addressed by this thesis. By using a developmental perspective, the definition of endogenous control has been enhanced.

One aspect of endogenous control can be defined by its ability to use context to create and maintain a task-goal. Unlike past research, this thesis isolated the influence of block predictiveness and found that the use of contextual information is developed by ages five and six and stays relatively stable until age 11; a finding which had been argued to only occur when measuring saccadic responses (Landry et al., 2019). Critically, my research showed that five- to six-year-olds were encouraged to use this higher-order skill even when the informativeness of the cue was not maximal, but this may be limited to situations which do not require frequent filtering of highly distracting items. This suggests that there are limits to when five- to six-year-olds are encouraged to engage endogenous control and may suggest that this age-group do not always use exogenous control as their default form of control in the Cued Visual Search task (Chevalier et al, 2015, 2020).

Some research would argue that cue-utilisation is a consequence of bottom-up priming effects. Cueing effects in the Low Predictive block are said to suggest that attention was guided in a bottom-up fashion (Theeuwes et al., 2006; Theeuwes & van der Burg, 2008) as the cues in this condition are highly irrelevant (66.67% invalid cues) and should be disregarded. Thus any cueing effects found in this condition is said to suggest cue-utilisation is a result of a feature priming effect (Theeuwes, 2013). At the same time, others have shown cueing effects for highly invalid blocks (>80% invalid) was a result of working memory maintenance for this item (Kiyonaga et al., 2012; Laarni, 2001). Nevertheless, I showed that cueing effects in the Mostly Predictive block were greater than the Low Predictive block as well as greater than the Baseline block where the cue did not match an item in the search-display. This provides strong evidence for the encouragement of volitional endogenous control in the Mostly Predictive block in both children and adults, which directly opposes the view that all feature cues lead to bottom-up priming (Theeuwes, 2013).

An additional aspect of this higher-order skill is its dependency on task demands. The use of endogenous control may be domain-specific as cue-use in Cued Visual Search and the AX-CPT did not have a predictive relationship in young and older adults. This could point to the influence of long-term task-goal representations which may be relied upon less in a task which requires adaptive adjustment of attentional weights to changing task-relevant features on a regular basis. Indeed, selection history with the cued feature may have adapted the task-goal (Bundesen et al., 2005; Carlisle et al., 2011; Woodman et al., 2013). Alternatively, there may be different forms of conflict experienced in the Cued Visual Search task and the AX-CPT (Gomez, Marco & Grau, 2003). Older adults have been shown to have a dampened ability to monitor response conflict both generally (Falkenstein, Hoormann & Hohnsbein, 2001) and in the AX-CPT (Hammerer et al., 2010); yielding smaller differences between BX and AY trials. In contrast to this, the Cued Visual Search task may measure conflict at the perceptual level whereby participants need to inhibit selection of the invalidly cued colour with less of an influence at the response level. Therefore, consideration of both accounts further highlights the importance for comparing performance in different experimental paradigms to gain a clearer understanding of these measures as well as expand our definition of the processes involved (Doebel et al., 2017).

A key characteristic of endogenous control is known as maintenance of early information, but its dependency on inhibitory processes was shown to change with age. Maintenance of task-relevant items is thought to be related to inhibition of task-irrelevant items (Beck et al., 2018; Moher & Egeth, 2012; Treisman & Sato, 1990). In adult-like and experienced forms of endogenous control, there is independence between maintenance and inhibition processes involved in the current variant of the Cued Visual Search task (Noonan et al., 2016). The distinction between these mechanisms suggests a lack of interdependence between these processes which could provide clarification for the lack of reduced capture by endogenous cues (Arita et al., 2012; Becker, Hemsteger & Peltier, 2015; Moher & Egeth, 2012; Moher et al., 2014). At a young age however, a cognitive trade-off can occur in individuals who have *transitioned* or have a good maintenance ability, which comes at a cost of a poorer inhibition ability. As such, encouragement of early maintenance processes in individuals who are still developing this skill may enhance the cognitive load of the task and incur a cost, rather than a benefit, on performance in situations of high interference (Blackwell & Munakata, 2014; Blackwell et al., 2014). By using a developmental approach, this thesis shows how age influences the interdependence between maintenance and inhibition skills in Cued Visual Search.

The role of endogenous cueing for overcoming attentional capture is less influential at early stages but could be modulated at a late stage of processing. Probabilistic cueing using contextual information, more time to encode the cue as well as enhancing reliance and selection of the cued feature did not lead to a reduction of attentional capture when the cue assisted search. Rather, a reduction of capture effects was found when attention was misinformed in both young and older adults. This could suggest that a reactive form of control which reactivates the cued feature at a late stage of processing, could modulate the effect of attentional capture by avoiding further interference from this item (Iarocci et al., 2009; Moher & Egeth, 2012). To further understand this dynamic, direct and indirect measures of attentional capture and intertrial manipulations would assess this claim. Next I will discuss relevant limitations specific to general areas of this research and propose future directions.

Limitations & Future Directions

In this section, I will first reflect on the limitations of this research and how they may have influenced my conclusions. I will propose areas in this research field which require further examination before making a concluding statement.

First, the singleton distracter used in this research was defined by bottom-up local contrast to surrounding items but it is possible that this item could be defined by a shared top-down feature. Low level vision dictates that the oriented edge or line of the diamond distracter would be processed at the same level as the orientation of the target line (Kerzel et al., 2018). This raises the possibility that attention could have been engaged by the singleton distracter (oriented 45°) as this item shared a target-defining feature (oriented 45°; Folk et al., 1992). This would suggest that endogenous cues were unable to override capture on the basis that capture was contingent on the task-goal which was to locate the tilted line; a low level feature which may have been shared by the singleton distracter. Although both items have similar low level features, the tilted line target and the singleton distracter were not colinear with one another as one was a line and the other was an edge and an object and so correspondence between them is less likely.

A second limitation is concerned with the endogenous cue-utilisation effects found in five- to six-year-olds. It should be noted that cue-utilisation performance in Chapters 3 and 5 was not explicitly compared, despite the use of the same method but with minor changes. There were a number of factors changed between these studies, one of which was the difference in the number of trials in each block condition. This could suggest that young children are only able to use endogenous control over short periods (Chapter 3: N = 144 trials; Chapter 5: N = 48 trials per block). Past research has shown that this age-group tend to use endogenous control on a trial-by-trial basis in the flanker, Simon and Stroop task (Ambrosi et al., 2016; N = 102 trials per block). In addition, cue-use on singleton-absent vs singleton-present trials did not significantly differ in Chapter 3 (*see Appendix 3.1*), suggesting that cueing ability was unimpaired by the singleton distracter in children and adults. Therefore, it is uncertain whether the singleton distracter impaired cue-use in five- to six-year-olds or if this age-group are only able to endogenously maintain early cues to guide attention for short interludes.

The measure of colour categorisation in Chapter 6 may not have been a sensitive measure. The reduced number of trials in each colour block condition (N = 15) meant that responses were averaged into smaller bins of three trials before a linear function was fitted to the data. In addition, research has shown that older adults tend to have greater difficulty distinguishing yellow and blue colours due to age-related changes in the visual lens which leads to items being tinted with yellow (Tamura & Sato, 2020). In Chapter 6, the slope scores for the yellow-blue block condition did not appear to deviate between participants in older adults (SD = .05) relative to their young counterparts (SD = .04). In addition, colour slope scores were close to ceiling performance in both age-groups (*see Appendix 6.3*). Altogether, it is possible that cue-utilisation in the Cued Visual Search task may have a level of priming, much like most tasks of this kind (Sawaki & Luck, 2014). In general, this task requires improvement in relation to its sensitivity, which in future cases could use a staircase procedure to acquire an individualised threshold for colour discriminability.

Moving on from the limitations, I will now consider possible future directions for this research. The current thesis aimed to understand whether an endogenous cue could override an attentional capture response, but less is known about where attention was deployed first in the search-display. The direction of the distance effects in Chapter 7 could indicate that attention was first deployed to the cued item before being captured by the singleton distracter. However, research has argued that the course of attentional capture and suppression effects requires both direct and indirect measurement of these processes (Gaspelin & Luck, 2018; Sawaki & Luck, 2010). The behavioural findings in the current thesis are defined as an indirect measure. It is recommended that saccadic fixations (Gaspelin et al., 2017) and ERP (Luck et al., 2021) provide direct measures of attentional deployment (N2pc) and attentional suppression (Pd) intrinsically related to the time-course of these processes. An additional behavioural measure which has been useful to assess engagement to target- vs distracter-related locations, is the inclusion of memory items (e.g. letters) in the search-display which is later probed (Chang et al., 2018). By using a dual approach of direct and indirect measures, this can further our knowledge in understanding the deployment of attentional processes in relation to their time-course.

Research has argued that the nature of the Cued Visual Search task means that participants have a reduced reliance on long-term task-goal representations (Carlisle et al., 2011; Woodman et a., 2013). The attentional control system may need to be flexible applying the attentional weights to the changing task-relevant features; meaning that the task-goal must be adapted in response to the cue (Bundesen et al., 2005). In correspondence with this, the revised signal suppression hypothesis states that intertrial effects can produce stimulus history which enables participants to adapt their task-goal and trigger an exogenous or reactive form of control (Luck et al., 2021). It is uncertain however whether intertrial effects are defined by bottom-up priming for repeated exposure to a cue colour (Theeuwes & van der Burg, 2011) or adjustment of the maintained task-goal (Bundesen et al., 2005; Woodman et al., 2013). Evidence has indicated that the repetition of a cued feature led to a reduction in attentional capture effects (Theeuwes & van der Burg, 2011) but this was not replicated by others using a similar task (Ásgeirsson & Kristjánsson, 2019). Neither of these studies included a baseline measure to compare cue repetition effects when the cue was mostly predictive vs irrelevant of the target. Thus, this field of research still has uncertainty with regard to the dynamics of bottom-up and top-down processes in the attentional selection of items in the Cued Visual Search task. By further considering the role of stimulus history on long-term task-goal representations, this research could gain a clearer depiction of these processes on attentional capture in the Mostly Predictive and Baseline blocks.

Conclusion

By considering the role of endogenous cue-utilisation and attentional capture across the lifespan, the current research has gained an enhanced definition of these processes as well as the dynamic between them. A developmental approach has shown that endogenous control is founded on its ability to use context to create and maintain a task-goal as well as its ability to change based on the demands of the task. The interdependence of this skill changes with increasing age but critically, it becomes adult-like by mid-childhood and retained in seniority. This domain-specific skill may play a lesser role in overcoming attentional capture when the task-goal is adapted on a regular basis. But reactivation of the task-goal at a late stage of processing may modulate the influence of further interference from a distraction. The current research is still ongoing and the findings will be further reviewed once data collection for Chapters 5-7 are complete. It is also of interest to assess whether online data collection influences the findings in Chapter 6 as this will allow us to explore how steps towards online studies influences attention research across the lifespan. Future research should engage in understanding the influence of selection history and long-term task-goal representations to further our understanding of the limits of endogenous cue-utilisation.

References

Abrahamse, E. L., & Van der Lubbe, R. H. J. (2008). Endogenous orienting modulates the Simon effect: critical factors in experimental design. *Psychol Res, 72*, 261–272. doi:10.1007/s00426-007-0110-x

Adams, R. C., & Chambers, C. D. (2012). Mapping the timecourse of goal-directed attention to location and colour in human vision. *Acta Psychol (Amst), 139*(3), 515-523. doi:10.1016/j.actpsy.2012.01.014

Ambrosi, S., Lemaire, P., & Blaye, A. (2016). Do Young Children Modulate Their Cognitive Control? *Exp Psychol, 63*(2), 117-126. doi:10.1027/1618-3169/a000320

Amso, D., & Scerif, G. (2015). The attentive brain: insights from developmental cognitive neuroscience. *Nat Rev Neurosci, 16*(10), 606-619. doi:10.1038/nrn4025

Andersen, S. K., Müller, M. M., & Hillyard, S. A. (2011). Tracking the allocation of attention in visual scenes with steady-state evoked potentials. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (Vol. 2, pp. 197-216): The Guilford Press.

Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proc Natl Acad Sci U S A, 108*(25), 10367-10371. doi:10.1073/pnas.1104047108

Anderson, G. M., Heinke, D., & Humphreys, G. W. (2011). Differential time course of implicit and explicit cueing by colour and orientation in visual search. *Visual Cognition, 19*(2), 258-288. doi:10.1080/13506285.2010.528985

Arita, J. T., Carlisle, N. B., & Woodman, G. F. (2012). Templates for rejection: configuring attention to ignore task-irrelevant features. *J Exp Psychol Hum Percept Perform, 38*(3), 580-584. doi:10.1037/a0027885

Ásgeirsson, Á. G., & Kristjánsson, Á. (2019). Attentional priming does not enable observers to ignore salient distractors. *Visual Cognition, 27*(5-8), 595-608. doi:10.1080/13506285.2019.1657215

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Percept Psychophys, 55*(5), 485-496. doi:10.3758/bf03205306

Barch, D. M., Braver, T. S., Nystrom, L. E., Forman, S. D., Noll, D. C., & Cohen, J. D. (1997). Dissociating working memory from task difficulty in human prefrontal cortex. *Neuropsychologia, 35*(10), 1373-1380. doi:10.1016/s0028-3932(97)00072-9

Barras, C., & Kerzel, D. (2017). Salient-but-irrelevant stimuli cause attentional capture in difficult, but attentional suppression in easy visual search. *Psychophysiology, 54*(12), 1826-1838. doi:10.1111/psyp.12962

Beck, V. M., Luck, S. J., & Hollingworth, A. (2018). Whatever you do, don't look at the...: Evaluating guidance by an exclusionary attentional template. *J Exp Psychol Hum Percept Perform, 44*(4), 645-662. doi:10.1037/xhp0000485

Becker, M. W., Hemsteger, S., & Peltier, C. (2015). No templates for rejection: A failure to configure attention to ignore task-irrelevant features. *Visual Cognition, 23*(9-10), 1150-1167. doi:10.1080/13506285.2016.1149532

Belopolsky, A. V., Zwaan, L., Theeuwes, J., & Kramer, A. F. (2007). The size of an attentional window modulates attentional capture by color singletons. *Psychon Bull Rev, 14*(5), 934-938. doi:10.3758/bf03194124

Benjamin, D. J., Berger, J. O., Johannesson, M., Nosek, B. A., Wagenmakers, E. J., Berk, R., . . . Johnson, V. E. (2018). Redefine statistical significance. *Nat Hum Behav, 2*(1), 6-10. doi:10.1038/s41562-017-0189-z

Berger, A., Henik, A., & Rafal, R. (2005). Competition between endogenous and exogenous orienting of visual attention. *Journal of Experimental Psychology: General, 134*(2), 207. doi:10.1037/0096-3445.134.2.207

Blackwell, K. A., Chatham, C. H., Wiseheart, M., & Munakata, Y. (2014). A developmental window into trade-offs in executive function: the case of task switching versus response inhibition in 6-year-olds. *Neuropsychologia, 62*, 356-364. doi:10.1016/j.neuropsychologia.2014.04.016

Blackwell, K. A., & Munakata, Y. (2014). Costs and benefits linked to developments in cognitive control. *Dev Sci, 17*(2), 203-211. doi:10.1111/desc.12113

Bornstein, M. H., & Korda, N. O. (1984). Discrimination and matching within and between hues measured by reaction times: some implications for categorical perception and levels of information processing. *Psychol Res, 46*(3), 207-222. doi:10.1007/BF00308884

Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends Cogn Sci, 16*(2), 106-113. doi:10.1016/j.tics.2011.12.010

Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neurosci Biobehav Rev, 26*(7), 809-817. doi:10.1016/s0149-7634(02)00067-2

Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., . . . Reed, B. R. (2001). Context processing in older adults: evidence for a theory relating cognitive control to neurobiology in healthy aging. *J Exp Psychol Gen, 130*(4), 746-763. doi:10.1037/0096-3445.130.4.746

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (Vol. 75, pp. 76-106): Oxford University Press, Inc.

Braver, T. S., Paxton, J. L., Locke, H. S., & Barch, D. M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *Proceedings of the National Academy of Sciences, 106*(18), 7351-7356. doi:10.1073/pnas.0808187106

Braver, T. S., Satpute, A. B., Rush, B. K., Racine, C. A., & Barch, D. M. (2005). Context processing and context maintenance in healthy aging and early stage dementia of the Alzheimer's type. *Psychol Aging, 20*(1), 33-46. doi:10.1037/0882-7974.20.1.33

Brodeur, D. A., & Boden, C. (2000). The effects of spatial uncertainty and cue predictability on visual orienting in children. *Cognitive Development, 15*(3), 367-382. doi:10.1016/s0885-2014(00)00025-3

Brodeur, D. A., & Enns, J. T. (1997). Covert visual orienting across the lifespan. *Can J Exp Psychol, 51*(1), 20-35. doi:10.1037/1196-1961.51.1.20

Bundesen, C. (1990). A theory of visual attention. *Psychol Rev, 97*(4), 523-547. doi:10.1037/0033-295x.97.4.523

Bundesen, C., Habekost, T., & Kyllingsbaek, S. (2005). A neural theory of visual attention: bridging cognition and neurophysiology. *Psychol Rev, 112*(2), 291-328. doi:10.1037/0033-295X.112.2.291

Burra, N., & Kerzel, D. (2013). Attentional capture during visual search is attenuated by target predictability: Evidence from the N 2pc, P d, and topographic segmentation. *Psychophysiology, 50*(5), 422-430. doi:10.1111/psyp.12019

Busel, C., Voracek, M., & Ansorge, U. (2020). A meta-analysis of contingent-capture effects. *Psychol Res, 84*(3), 784-809. doi:10.1007/s00426-018-1087-3

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: the HAROLD model. *Psychol Aging, 17*(1), 85-100. doi:10.1037//0882-7974.17.1.85

Carlisle, N. B., Arita, J. T., Pardo, D., & Woodman, G. F. (2011). Attentional templates in visual working memory. *J Neurosci, 31*(25), 9315-9322. doi:10.1523/JNEUROSCI.1097-11.2011

Carlisle, N. B., & Woodman, G. F. (2011). Automatic and strategic effects in the guidance of attention by working memory representations. *Acta Psychol (Amst), 137*(2), 217-225. doi:10.1016/j.actpsy.2010.06.012

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Dev Neuropsychol, 28*(2), 595-616. doi:10.1207/s15326942dn2802_3

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science, 280*(5364), 747-749. doi:10.1126/science.280.5364.747

Chang, S., Cunningham, C. A., & Egeth, H. E. (2019). The power of negative thinking: Paradoxical but effective ignoring of salient-but-irrelevant stimuli with a spatial cue. *Visual Cognition, 27*(3-4), 199-213. doi:10.1080/13506285.2018.1541950

Chatham, C. H., Frank, M. J., & Munakata, Y. (2009). Pupillometric and behavioral markers of a developmental shift in the temporal dynamics of cognitive control. *Proc Natl Acad Sci U S A, 106*(14), 5529-5533. doi:10.1073/pnas.0810002106

Cheal, M., & Chastain, G. (2002). Timing of facilitatory and inhibitory effects of visual attention. *Visual Cognition, 9*(8), 969-1002. doi:10.1080/13506280143000467

Chen, Z., & Cave, K. R. (2016). Zooming in on the cause of the perceptual load effect in the go/no-go paradigm. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(8), 1072. doi:10.1037/xhp0000168

Chevalier, N., & Blaye, A. (2016). Metacognitive Monitoring of Executive Control Engagement During Childhood. *Child Dev, 87*(4), 1264-1276. doi:10.1111/cdev.12537

Chevalier, N., Blaye, A., Dufau, S., & Lucenet, J. (2010). What visual information do children and adults consider while switching between tasks? Eye-tracking investigation of cognitive flexibility development. *Developmental Psychology, 46*(4), 955. doi:10.1037/a0019674

Chevalier, N., Martis, S. B., Curran, T., & Munakata, Y. (2015). Metacognitive processes in executive control development: the case of reactive and proactive control. *J Cogn Neurosci, 27*(6), 1125-1136. doi:10.1162/jocn_a_00782

Chevalier, N., Meaney, J. A., Traut, H. J., & Munakata, Y. (2020). Adaptiveness in proactive control engagement in children and adults. *Dev Cogn Neurosci, 46*, 100870. doi:10.1016/j.dcn.2020.100870

Christie, G. J., Spalek, T. M., & McDonald, J. J. (2018). Salience drives overt selection of two equally relevant visual targets. *Atten Percept Psychophys, 80*(6), 1342-1349. doi:10.3758/s13414-018-1555-2

Chun, M. M. (2000). Contextual cueing of visual attention. *Trends Cogn Sci, 4*(5), 170-178. doi:10.1016/s1364-6613(00)01476-5

Clapp, W. C., & Gazzaley, A. (2012). Distinct mechanisms for the impact of distraction and interruption on working memory in aging. *Neurobiol Aging, 33*(1), 134-148. doi:10.1016/j.neurobiolaging.2010.01.012

Cohen, J. R., Sreenivasan, K. K., & D'Esposito, M. (2014). Correspondence between stimulus encoding-and maintenance-related neural processes underlies successful working memory. *Cerebral cortex, 24*(3), 593-599. doi:10.1093/cercor/bhs339

Corbetta, M., Kincade, J. M., Ollinger, J. M., McAvoy, M. P., & Shulman, G. L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature neuroscience, 3*(3), 292-297. doi:10.1038/74905

Corbetta, M., Kincade, J. M., & Shulman, G. L. (2002). Neural systems for visual orienting and their relationships to spatial working memory. *Journal of Cognitive Neuroscience, 14*(3), 508-523. doi:10.1162/089892902317362029

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nat Rev Neurosci, 3*(3), 201-215. doi:10.1038/nrn755

Cosman, J. D., & Vecera, S. P. (2010a). Attentional capture under high perceptual load. *Psychonomic bulletin & review*, *17*(6), 815-820. doi: 10.3758/PBR.17.6.815

Cosman, J. D., & Vecera, S. P. (2010b). Attentional capture by motion onsets is modulated by perceptual load. *Attention, Perception, & Psychophysics*, *72*(8), 2096-2105. doi: 10.3758/BF03196686

Costello, M. C., Madden, D. J., Shepler, A. M., Mitroff, S. R., & Leber, A. B. (2010). Age-related preservation of top-down control over distraction in visual search. *Exp Aging Res, 36*(3), 249-272. doi:10.1080/0361073X.2010.484719

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current directions in psychological science, 19*(1), 51-57. doi:10.1177/0963721409359277

Cowan, N. (2011). The focus of attention as observed in visual working memory tasks: Making sense of competing claims. *Neuropsychologia, 49*(6), 1401-1406. doi:10.1016/j.neuropsychologia.2011.01.035

Cowan, N., Elliott, E. M., Scott Saults, J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. (2005). On the capacity of attention: its estimation and its role in working memory and cognitive aptitudes. *Cogn Psychol, 51*(1), 42-100. doi:10.1016/j.cogpsych.2004.12.001

Cowan, N., Morey, C. C., AuBuchon, A. M., Zwilling, C. E., & Gilchrist, A. L. (2010). Seven-year-olds allocate attention like adults unless working memory is overloaded. *Developmental Science, 13*(1), 120-133. doi:10.1111/j.1467-7687.2009.00864.x

Czernochowski, D. (2014). Conflict Monitoring Across the Life Span. *Journal of Psychophysiology, 28*(3), 124-135. doi:10.1027/0269-8803/a000120

D'Amico, E. J., Neilands, T. B., & Zambarano, R. (2001). Power analysis for multivariate and repeated measures designs: a flexible approach using the SPSS MANOVA procedure. *Behav Res Methods Instrum Comput, 33*(4), 479-484. doi:10.3758/bf03195405

Daoutis, C. A., Pilling, M., & Davies, I. R. (2006). Categorical effects in visual search for colour. *Visual Cognition, 14*(2), 217-240. doi:10.1080/13506280500158670

Diamond, A. (2013). Executive functions. *Annu Rev Psychol, 64*, 135-168. doi:10.1146/annurev-psych-113011-143750

DiGirolamo, G. J., Kramer, A. F., Barad, V., Cepeda, N. J., Weissman, D. H., Milham, M. P., . . . McAuley, E. (2001). General and task-specific frontal lobe recruitment in older adults during executive processes: a fMRI investigation of task-switching. *Neuroreport, 12*(9), 2065-2071. doi:10.1097/00001756-200107030-00054

Doebel, S., Barker, J. E., Chevalier, N., Michaelson, L. E., Fisher, A. V., & Munakata, Y. (2017). Getting ready to use control: Advances in the measurement of young children's use of proactive control. *PloS one, 12*(4), e0175072. doi:10.1371/journal.pone.0175072

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychol Rev, 96*(3), 433-458. doi:10.1037/0033-295x.96.3.433

Dye, M. W., & Bavelier, D. (2010). Differential development of visual attention skills in school-age children. *Vision Res, 50*(4), 452-459. doi:10.1016/j.visres.2009.10.010

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and clinical neurophysiology, 99*(3), 225-234. doi:10.1016/0013-4694(96)95711-9

Eimer, M., & Kiss, M. (2008). Involuntary attentional capture is determined by task set: evidence from event-related brain potentials. *J Cogn Neurosci, 20*(8), 1423-1433. doi:10.1162/jocn.2008.20099

Eimer, M., Kiss, M., & Nicholas, S. (2011). What top-down task sets do for us: An ERP study on the benefits of advance preparation in visual search. *Journal of Experimental Psychology: Human Perception and Performance, 37*(6), 1758. doi:10.1037/a0024326

Elke, S., & Wiebe, S. A. (2017). Proactive control in early and middle childhood: An ERP study. *Dev Cogn Neurosci, 26*, 28-38. doi:10.1016/j.dcn.2017.04.005

Engle, R. W. (2010). Role of working-memory capacity in cognitive control. *Current anthropology, 51*(S1), S17-S26. doi:10.1086/650572

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. H. Ross (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 44, pp. 145-199): Elsevier.

Erickson, L. C., Thiessen, E. D., Godwin, K. E., Dickerson, J. P., & Fisher, A. V. (2015). Endogenously and exogenously driven selective sustained attention: Contributions to learning in kindergarten children. *J Exp Child Psychol, 138*, 126-134. doi:10.1016/j.jecp.2015.04.011

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (2001). Changes of error-related ERPs with age. *Exp Brain Res, 138*(2), 258-262. doi:10.1007/s002210100712

Farell, B., & Pelli, D. G. (1993). Can we attend to large and small at the same time? *Vision Research, 33*(18), 2757-2772. doi:10.1016/0042-6989(93)90234-N

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods, 41*(4), 1149-1160. doi:10.3758/BRM.41.4.1149

Feldmann-Wüstefeld, T., & Schubö, A. (2013). Context homogeneity facilitates both distractor inhibition and target enhancement. *Journal of Vision, 13*(3), 11-11. doi:10.1167/13.3.11

Fisher, A. V., Godwin, K. E., & Seltman, H. (2014). Visual environment, attention allocation, and learning in young children: when too much of a good thing may be bad. *Psychol Sci, 25*(7), 1362-1370. doi:10.1177/0956797614533801

Folk, C. L., & Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons: evidence for two forms of attentional capture. *J Exp Psychol Hum Percept Perform, 24*(3), 847-858. doi:10.1037//0096-1523.24.3.847

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *J Exp Psychol Hum Percept Perform, 18*(4), 1030-1044. doi:10.1037/0096-1523.18.4.1030

Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: contingent attentional capture by apparent motion, abrupt onset, and color. *J Exp Psychol Hum Percept Perform, 20*(2), 317-329. doi:10.1037//0096-1523.20.2.317

Forster, S., & Lavie, N. (2008). Failures to ignore entirely irrelevant distractors: the role of load. *J Exp Psychol Appl, 14*(1), 73-83. doi:10.1037/1076-898X.14.1.73

Found, A., & Muller, H. J. (1996). Searching for unknown feature targets on more than one dimension: investigating a "dimension-weighting" account. *Percept Psychophys, 58*(1), 88-101. doi:10.3758/bf03205479

Franklin, A., & Davies, I. R. L. (2004). New evidence for infant colour categories. *British Journal of Developmental Psychology, 22*(3), 349-377. doi:10.1348/0261510041552738

Franklin, A., Pilling, M., & Davies, I. (2005). The nature of infant color categorization: evidence from eye movements on a target detection task. *J Exp Child Psychol, 91*(3), 227-248. doi:10.1016/j.jecp.2005.03.003

Fukuda, K., & Vogel, E. K. (2009). Human variation in overriding attentional capture. *J Neurosci, 29*(27), 8726-8733. doi:10.1523/JNEUROSCI.2145-09.2009

Fukuda, K., & Vogel, E. K. (2011). Individual differences in recovery time from attentional capture. *Psychol Sci, 22*(3), 361-368. doi:10.1177/0956797611398493

Gaspar, J. M., Christie, G. J., Prime, D. J., Jolicoeur, P., & McDonald, J. J. (2016). Inability to suppress salient distractors predicts low visual working memory capacity. *Proc Natl Acad Sci U S A, 113*(13), 3693-3698. doi:10.1073/pnas.1523471113

Gaspar, J. M., & McDonald, J. J. (2014). Suppression of salient objects prevents distraction in visual search. *J Neurosci, 34*(16), 5658-5666. doi:10.1523/JNEUROSCI.4161-13.2014

Gaspelin, N., Leonard, C. J., & Luck, S. J. (2015). Direct Evidence for Active Suppression of Salient-but-Irrelevant Sensory Inputs. *Psychol Sci, 26*(11), 1740-1750. doi:10.1177/0956797615597913

Gaspelin, N., Leonard, C. J., & Luck, S. J. (2017). Suppression of overt attentional capture by salient-but-irrelevant color singletons. *Atten Percept Psychophys, 79*(1), 45-62. doi:10.3758/s13414-016-1209-1

Gaspelin, N., & Luck, S. J. (2018). Distinguishing among potential mechanisms of singleton suppression. *Journal of Experimental Psychology: Human Perception and Performance, 44*(4), 626. doi:10.1037/xhp0000484

Gaspelin, N., Margett-Jordan, T., & Ruthruff, E. (2015). Susceptible to distraction: children lack top-down control over spatial attention capture. *Psychon Bull Rev, 22*(2), 461-468. doi:10.3758/s13423-014-0708-0

Godwin, K., & Fisher, A. (2011). *Allocation of attention in classroom environments: Consequences for learning*. Paper presented at the Proceedings of the annual meeting of the Cognitive Science Society.

Goldberg, M. C., Maurer, D., & Lewis, T. L. (2001). Developmental changes in attention: the effects of endogenous cueing and of distractors. *Developmental Science, 4*(2), 209-219. doi:10.1111/1467-7687.00166

Gomez, C. M., Marco, J., & Grau, C. (2003). Preparatory visuo-motor cortical network of the contingent negative variation estimated by current density. *Neuroimage*, *20*(1), 216-224. doi: 10.1016/S1053-8119(03)00295-7

Gonthier, C., Macnamara, B. N., Chow, M., Conway, A. R., & Braver, T. S. (2016). Inducing Proactive Control Shifts in the AX-CPT. *Front Psychol, 7*, 1822. doi:10.3389/fpsyg.2016.01822

Gonthier, C., Zira, M., Cole, P., & Blaye, A. (2019). Evidencing the developmental shift from reactive to proactive control in early childhood and its relationship to working memory. *J Exp Child Psychol, 177*, 1-16. doi:10.1016/j.jecp.2018.07.001

Gottlieb, J., & Snyder, L. H. (2010). Spatial and non-spatial functions of the parietal cortex. *Curr Opin Neurobiol, 20*(6), 731-740. doi:10.1016/j.conb.2010.09.015

Grady, C. L. (2008). Cognitive neuroscience of aging. *Ann N Y Acad Sci, 1124*(1), 127-144. doi:10.1196/annals.1440.009

Greenwood, P. M., & Parasuraman, R. (2004). The scaling of spatial attention in visual search and its modification in healthy aging. *Percept Psychophys, 66*(1), 3-22. doi:10.3758/bf03194857

Gunseli, E., Olivers, C. N., & Meeter, M. (2014). Effects of search difficulty on the selection, maintenance, and learning of attentional templates. *J Cogn Neurosci, 26*(9), 2042-2054. doi:10.1162/jocn_a_00600

Haarmann, H. J., Ashling, G. E., Davelaar, E. J., & Usher, M. (2005). Age-related declines in context maintenance and semantic short-term memory. *Q J Exp Psychol A, 58*(1), 34-53. doi:10.1080/02724980443000214

Hahn, S., & Buttaccio, D. R. (2018). Aging and guided visual search: the role of visual working memory. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn, 25*(4), 535-549. doi:10.1080/13825585.2017.1344185

Hamker, F. H. (2004). A dynamic model of how feature cues guide spatial attention. *Vision Research, 44*(5), 501-521. doi:10.1016/j.visres.2003.09.033

Hammerer, D., Li, S. C., Muller, V., & Lindenberger, U. (2010). An electrophysiological study of response conflict processing across the lifespan: assessing the roles of conflict monitoring, cue utilization, response anticipation, and response suppression. *Neuropsychologia, 48*(11), 3305-3316. doi:10.1016/j.neuropsychologia.2010.07.014

Hannus, A., Bekkering, H., & Cornelissen, F. W. (2020). Preview of partial stimulus information in search prioritizes features and conjunctions, not locations. *Attention, Perception, & Psychophysics, 82*(1), 140-152. doi:10.3758/s13414-019-01841-1

Hayward, D. A., & Ristic, J. (2013). Measuring attention using the Posner cuing paradigm: the role of across and within trial target probabilities. *Frontiers in Human Neuroscience, 7*, 205. doi:10.3389/fnhum.2013.00205

Hedges, L., & Olkin, I. (1985). *Statistical Methods for Meta-Analysis*: Academic Press.

Heim, S., & Keil, A. (2012). Developmental trajectories of regulating attentional selection over time. *Front Psychol, 3*, 277. doi:10.3389/fpsyg.2012.00277

Henderickx, D., Maetens, K., & Soetens, E. (2010). Feature integration and spatial attention: common processes for endogenous and exogenous orienting. *Psychol Res, 74*(3), 239-254. doi:10.1007/s00426-009-0251-1

Hermens, F. (2018). When do arrows start to compete? A developmental mouse-tracking study. *Acta Psychol (Amst), 182*, 177-188. doi:10.1016/j.actpsy.2017.11.015

Hickey, C., Di Lollo, V., & McDonald, J. J. (2009). Electrophysiological indices of target and distractor processing in visual search. *J Cogn Neurosci, 21*(4), 760-775. doi:10.1162/jocn.2009.21039

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *J Cogn Neurosci, 18*(4), 604-613. doi:10.1162/jocn.2006.18.4.604

Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science, 182*(4108), 177-180. doi:10.1126/science.182.4108.177

Hillyard, S. A., & Munte, T. F. (1984). Selective attention to color and location: an analysis with event-related brain potentials. *Percept Psychophys, 36*(2), 185-198. doi:10.3758/bf03202679

Hopf, J. M., Boehler, C. N., Luck, S. J., Tsotsos, J. K., Heinze, H. J., & Schoenfeld, M. A. (2006). Direct neurophysiological evidence for spatial suppression surrounding the focus of attention in vision. *Proc Natl Acad Sci U S A, 103*(4), 1053-1058. doi:10.1073/pnas.0507746103

Howard Jr, J. H., Howard, D. V., Dennis, N. A., Yankovich, H., & Vaidya, C. J. (2004). Implicit spatial contextual learning in healthy aging. *Neuropsychology, 18*(1), 124. doi:10.1037/0894-4105.18.1.124

Huang, C.-M., Polk, T. A., Goh, J. O., & Park, D. C. (2012). Both left and right posterior parietal activations contribute to compensatory processes in normal aging. *Neuropsychologia, 50*(1), 55-66. doi:10.1016/j.neuropsychologia.2011.10.022

Humphrey, D. G., & Kramer, A. F. (1997). Age differences in visual search for feature, conjunction, and triple-conjunction targets. *Psychol Aging, 12*(4), 704-717. doi:10.1037//0882-7974.12.4.704

Humphreys, G. W. (2016). Feature confirmation in object perception: Feature integration theory 26 years on from the Treisman Bartlett lecture. *Q J*

Exp Psychol (Hove), 69(10), 1910-1940. doi:10.1080/17470218.2014.988736

Humphreys, G. W., & Muller, H. J. (1993). SEarch via Recursive Rejection (SERR): A connectionist model of visual search. *Cognitive Psychology, 25*(1), 43-110. doi:10.1006/cogp.1993.1002

Iarocci, G., Enns, J. T., Randolph, B., & Burack, J. A. (2009). The modulation of visual orienting reflexes across the lifespan. *Dev Sci, 12*(5), 715-724. doi:10.1111/j.1467-7687.2009.00810.x

Isbell, E., Calkins, S. D., Swingler, M. M., & Leerkes, E. M. (2018). Attentional fluctuations in preschoolers: Direct and indirect relations with task accuracy, academic readiness, and school performance. *J Exp Child Psychol, 167*, 388-403. doi:10.1016/j.jecp.2017.11.013

Iselin, A. M., & Decoster, J. (2009). Reactive and proactive control in incarcerated and community adolescents and young adults. *Cogn Dev, 24*(2), 192-206. doi:10.1016/j.cogdev.2008.07.001

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nat Rev Neurosci, 2*(3), 194-203. doi:10.1038/35058500

Jakobsen, K. V., Frick, J. E., & Simpson, E. A. (2013). Look Here! The Development of Attentional Orienting to Symbolic Cues. *Journal of Cognition and Development, 14*(2), 229-249. doi:10.1080/15248372.2012.666772

Jannati, A., Gaspar, J. M., & McDonald, J. J. (2013). Tracking target and distractor processing in fixed-feature visual search: evidence from human electrophysiology. *J Exp Psychol Hum Percept Perform, 39*(6), 1713-1730. doi:10.1037/a0032251

Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Front Hum Neurosci, 4*, 186. doi:10.3389/fnhum.2010.00186

Jiang, Y. V., Sigstad, H. M., & Swallow, K. M. (2013). The time course of attentional deployment in contextual cueing. *Psychon Bull Rev, 20*(2), 282-288. doi:10.3758/s13423-012-0338-3

Johnson, K. A., Lewis, F. C., & Cornish, K. M. (2020). A child-focused version of the Attention Network Task designed to investigate interactions between the attention networks, including the endogenous orienting network. *Child Neuropsychol, 26*(5), 666-690. doi:10.1080/09297049.2019.1702635

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. *Attention and performance*, 187-203.

Juola, J. F., Koshino, H., Warner, C. B., McMickell, M., & Peterson, M. (2000). Automatic and voluntary control of attention in young and older adults. *Am J Psychol, 113*(2), 159-178. doi:10.2307/1423726

Kasten, R., & Navon, D. (2008). Is location cueing inherently superior to color cueing? Not if color is presented early enough. *Acta Psychologica, 127*(1), 89-102. doi:10.1016/j.actpsy.2007.02.002

Kawahara, J., & Miyatani, M. (2001). The effect of informative and uninformative cueing of attention on feature integration. *J Gen Psychol, 128*(1), 57-75. doi:10.1080/00221300109598898

Kelly, K. L., & Judd, D. B. (1955). *The ISCC-NBS method of designating colors and a dictionary of color names* (Vol. 553): US Department of Commerce, National Bureau of Standards.

Kennedy, K. M., & Raz, N. (2009). Aging white matter and cognition: differential effects of regional variations in diffusion properties on memory, executive functions, and speed. *Neuropsychologia, 47*(3), 916-927. doi:10.1016/j.neuropsychologia.2009.01.001

Kerzel, D., Barras, C., & Grubert, A. (2018). Suppression of salient stimuli inside the focus of attention. *Biol Psychol, 139*, 106-114. doi:10.1016/j.biopsycho.2018.10.010

Kharitonova, M., Martin, R. E., Gabrieli, J. D., & Sheridan, M. A. (2013). Cortical gray-matter thinning is associated with age-related improvements on executive function tasks. *Developmental cognitive neuroscience, 6*, 61-71. doi:10.1016/j.dcn.2013.07.002

Kharitonova, M., Winter, W., & Sheridan, M. A. (2015). As working memory grows: A developmental account of neural bases of working memory capacity in 5-to 8-year old children and adults. *Journal of Cognitive Neuroscience, 27*(9), 1775-1788. doi:10.1162/jocn_a_00824

Kim, Y. H., Gitelman, D. R., Nobre, A. C., Parrish, T. B., LaBar, K. S., & Mesulam, M. M. (1999). The large-scale neural network for spatial attention displays multifunctional overlap but differential asymmetry. *Neuroimage, 9*(3), 269-277. doi:10.1006/nimg.1999.0408

Kiyonaga, A., Egner, T., & Soto, D. (2012). Cognitive control over working memory biases of selection. *Psychon Bull Rev, 19*(4), 639-646. doi:10.3758/s13423-012-0253-7

Kovacs, I., & Julesz, B. (1993). A closed curve is much more than an incomplete one: Effect of closure in figure-ground segmentation. *Proceedings of the National Academy of Sciences, 90*(16), 7495-7497. doi:10.1073/pnas.90.16.7495

Kovács, I., & Julesz, B. (1994). Perceptual sensitivity maps within globally defined visual shapes. *Nature, 370*(6491), 644-646. doi:10.1038/370644a0

Kramer, A. F., Hahn, S., Irwin, D. E., & Theeuwes, J. (1999). Attentional capture and aging: implications for visual search performance and oculomotor control. *Psychol Aging, 14*(1), 135-154. doi:10.1037//0882-7974.14.1.135

Kramer, A. F., Hahn, S., Irwin, D. E., & Theeuwes, J. (1999). Attentional capture and aging: implications for visual search performance and oculomotor control. *Psychol Aging, 14*(1), 135-154. doi:10.1037//0882-7974.14.1.135

Kramer, A. F., Humphrey, D. G., Larish, J. F., Logan, G. D., & Strayer, D. L. (1994). Aging and inhibition: beyond a unitary view of inhibitory processing in attention. *Psychol Aging, 9*(4), 491-512.

Kray, J., Ferdinand, N. K., & Stenger, K. (2020). Training and Transfer of Cue Updating in Older Adults Is Limited: Evidence From Behavioral and Neuronal Data. *Frontiers in Human Neuroscience, 14*, 492. doi:10.3389/fnhum.2020.565927

Kray, J., Schmitt, H., Heintz, S., & Blaye, A. (2015). Does verbal labeling influence age differences in proactive and reactive cognitive control? *Developmental Psychology, 51*(3), 378. doi:10.1037/a0038795

Kubota, M., Hadley, L. V., Schaeffner, S., Könen, T., Meaney, J.-A., Auyeung, B., . . . Chevalier, N. (2020). Consistent use of proactive control and relation with academic achievement in childhood. *Cognition, 203*, 104329. doi:10.1016/j.cognition.2020.104329

Kumar, S., Soto, D., & Humphreys, G. W. (2009). Electrophysiological evidence for attentional guidance by the contents of working memory. *Eur J Neurosci, 30*(2), 307-317. doi:10.1111/j.1460-9568.2009.06805.x

Laarni, J. (2001). Colour-cueing in visual search. *Scand J Psychol, 42*(1), 71-78. doi:10.1111/1467-9450.00215

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol, 4*, 863. doi:10.3389/fpsyg.2013.00863

Lakens, D., Adolfi, F. G., Albers, C. J., Anvari, F., Apps, M. A., Argamon, S. E., . . . Bradford, D. E. (2018). Justify your alpha. *Nature human behaviour, 2*(3), 168-171. doi:10.1038/s41562-018-0311-x

Lamy, D., Leber, A., & Egeth, H. E. (2004). Effects of task relevance and stimulus-driven salience in feature-search mode. *J Exp Psychol Hum Percept Perform, 30*(6), 1019-1031. doi:10.1037/0096-1523.30.6.1019

Lancaster, H. O., & Seneta, E. (2005). Chi-square distribution. *Encyclopedia of biostatistics, 2*. doi:10.1002/0470011815.b2a15018

Landry, O., Johnson, K. A., Fleming, S. J., Crewther, S. G., & Chouinard, P. A. (2019). A new look at the developmental profile of visual endogenous orienting. *J Exp Child Psychol, 183*, 158-171. doi:10.1016/j.jecp.2019.01.022

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*(3), 451. doi:10.1037/0096-1523.21.3.451

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *J Exp Psychol Gen, 133*(3), 339-354. doi:10.1037/0096-3445.133.3.339

Leber, A. B., & Egeth, H. E. (2006). It's under control: top-down search strategies can override attentional capture. *Psychon Bull Rev, 13*(1), 132-138. doi:10.3758/bf03193824

Leclercq, V., & Sieroff, E. (2013). Development of endogenous orienting of attention in school-age children. *Child Neuropsychol, 19*(4), 400-419. doi:10.1080/09297049.2012.682568

Lewis, F. C., Reeve, R. A., & Johnson, K. A. (2018). A longitudinal analysis of the attention networks in 6- to 11-year-old children. *Child Neuropsychol, 24*(2), 145-165. doi:10.1080/09297049.2016.1235145

Li, L., Gratton, C., Fabiani, M., & Knight, R. T. (2013). Age-related frontoparietal changes during the control of bottom-up and top-down attention: an ERP study. *Neurobiol Aging, 34*(2), 477-488. doi:10.1016/j.neurobiolaging.2012.02.025

Li, L., Gratton, C., Yao, D., & Knight, R. T. (2010). Role of frontal and parietal cortices in the control of bottom-up and top-down attention in humans. *Brain Res, 1344*, 173-184. doi:10.1016/j.brainres.2010.05.016

Lien, M. C., Gemperle, A., & Ruthruff, E. (2011). Aging and involuntary attention capture: electrophysiological evidence for preserved attentional control with advanced age. *Psychol Aging, 26*(1), 188-202. doi:10.1037/a0021073

Lien, M. C., Ruthruff, E., Goodin, Z., & Remington, R. W. (2008). Contingent attentional capture by top-down control settings: converging evidence from event-related potentials. *J Exp Psychol Hum Percept Perform, 34*(3), 509-530. doi:10.1037/0096-1523.34.3.509

Lien, M. C., Ruthruff, E., & Johnston, J. C. (2010). Attentional capture with rapidly changing attentional control settings. *J Exp Psychol Hum Percept Perform, 36*(1), 1-16. doi:10.1037/a0015875

Liesefeld, H. R., Liesefeld, A. M., Pollmann, S., & Müller, H. J. (2018). Biasing allocations of attention via selective weighting of saliency signals:

Behavioral and neuroimaging evidence for the dimension-weighting account. In T. Hodgson (Ed.), *Processes of Visuospatial Attention and Working Memory* (Vol. 41, pp. 87-113): Springer, Cham.

Liesefeld, H. R., Liesefeld, A. M., Tollner, T., & Muller, H. J. (2017). Attentional capture in visual search: Capture and post-capture dynamics revealed by EEG. *Neuroimage, 156*, 166-173. doi:10.1016/j.neuroimage.2017.05.016

Liu, T. (2019). Feature-based attention: effects and control. *Curr Opin Psychol, 29*, 187-192. doi:10.1016/j.copsyc.2019.03.013

Lleras, A., Chu, H., & Buetti, S. (2017). Can we “apply” the findings of Forster and Lavie (2008)? On the generalizability of attentional capture effects under varying levels of perceptual load. *Journal of Experimental Psychology: Applied*, *23*(2), 158. doi: 10.1037/xap0000116

Lookadoo, R., Yang, Y., & Merrill, E. C. (2017). Encouraging top-down attention in visual search:A developmental perspective. *Atten Percept Psychophys, 79*(7), 2007-2020. doi:10.3758/s13414-017-1379-5

Lorsbach, T. C., & Reimer, J. F. (2008). Context processing and cognitive control in children and young adults. *J Genet Psychol, 169*(1), 34-50. doi:10.3200/GNTP.169.1.34-50

Lorsbach, T. C., & Reimer, J. F. (2011). Developmental differences in the use of task goals in a cued version of the stroop task. *Br J Dev Psychol, 29*(Pt 1), 138-147. doi:10.1111/j.2044-835X.2010.02011.x

Lucenet, J., & Blaye, A. (2014). Age-related changes in the temporal dynamics of executive control: a study in 5- and 6-year-old children. *Front Psychol, 5*, 831. doi:10.3389/fpsyg.2014.00831

Lucenet, J., & Blaye, A. (2019). What do I do next? The influence of two self-cueing strategies on children’s engagement of proactive control. *Cognitive Development, 50*, 167-176. doi:10.1016/j.cogdev.2019.05.001

Luck, S. J., Gaspelin, N., Folk, C. L., Remington, R. W., & Theeuwes, J. (2021). Progress Toward Resolving the Attentional Capture Debate. *Vis cogn, 29*(1), 1-21. doi:10.1080/13506285.2020.1848949

Luna, B., Garver, K. E., Urban, T. A., Lazar, N. A., & Sweeney, J. A. (2004). Maturation of cognitive processes from late childhood to adulthood. *Child Dev, 75*(5), 1357-1372. doi:10.1111/j.1467-8624.2004.00745.x

Lustig, C., Hasher, L., & Zacks, R. T. (2007). Inhibitory deficit theory: Recent developments in a "new view". In D. S. Gorfein & C. M. MacLeod (Eds.), *Inhibition in cognition* (pp. 145–162): American Psychological Association.

Madden, D. J. (2007). Aging and Visual Attention. *Curr Dir Psychol Sci, 16*(2), 70-74. doi:10.1111/j.1467-8721.2007.00478.x

Madden, D. J., & Plude, D. J. (1993). Selective preservation of selective attention. In J. Cerella, J. M. Rybash, W. Hoyer, & M. L. Commons (Eds.), *Adult information processing: Limits on loss* (pp. 273-300): Academic Press.

Madden, D. J., Whiting, W. L., Cabeza, R., & Huettel, S. A. (2004). Age-related preservation of top-down attentional guidance during visual search. *Psychol Aging, 19*(2), 304-309. doi:10.1037/0882-7974.19.2.304

Mäki-Marttunen, V., Hagen, T., & Espeseth, T. (2019). Task context load induces reactive cognitive control: An fMRI study on cortical and brain stem activity. *Cognitive, Affective, & Behavioral Neuroscience, 19*(4), 945-965. doi:10.3758/s13415-019-00691-6

Marcovitch, S., Boseovski, J. J., Knapp, R. J., & Kane, M. J. (2010). Goal neglect and working memory capacity in 4- to 6-year-old children. *Child Dev, 81*(6), 1687-1695. doi:10.1111/j.1467-8624.2010.01503.x

Martín-Arévalo, E., Lupiáñez, J., Botta, F., & Chica, A. B. (2015). Endogenous attention modulates attentional and motor interference from distractors: Evidence from behavioral and electrophysiological results. *Frontiers in Psychology, 6,* 132. doi: 10.3389/fpsyg.2015.00132

Martinovic, J., Wuerger, S. M., Hillyard, S. A., Muller, M. M., & Andersen, S. K. (2018). Neural mechanisms of divided feature-selective attention to colour. *Neuroimage, 181*, 670-682. doi:10.1016/j.neuroimage.2018.07.033

Mayer, A. R., Dorflinger, J. M., Rao, S. M., & Seidenberg, M. (2004). Neural networks underlying endogenous and exogenous visual-spatial orienting. *Neuroimage, 23*(2), 534-541. doi:10.1016/j.neuroimage.2004.06.027

Merrill, E. C., & Conners, F. A. (2013). Age-related interference from irrelevant distracters in visual feature search among heterogeneous distracters. *Journal of experimental child psychology, 115*(4), 640-654. doi:10.1016/j.jecp.2013.03.013

Mertes, C., Wascher, E., & Schneider, D. (2016). From Capture to Inhibition: How does Irrelevant Information Influence Visual Search? Evidence from a Spatial Cuing Paradigm. *Front Hum Neurosci, 10*, 232. doi:10.3389/fnhum.2016.00232

Mevorach, C., Hodsoll, J., Allen, H., Shalev, L., & Humphreys, G. (2010). Ignoring the elephant in the room: a neural circuit to downregulate salience. *J Neurosci, 30*(17), 6072-6079. doi:10.1523/JNEUROSCI.0241-10.2010

Mevorach, C., Humphreys, G. W., & Shalev, L. (2005). Attending to local form while ignoring global aspects depends on handedness: evidence from TMS. *Nature neuroscience, 8*(3), 276-277. doi:10.1038/nn1400

Mevorach, C., Humphreys, G. W., & Shalev, L. (2009). Reflexive and preparatory selection and suppression of salient information in the right and left posterior parietal cortex. *J Cogn Neurosci, 21*(6), 1204-1214. doi:10.1162/jocn.2009.21088

Michael, G. A., Lete, B., & Ducrot, S. (2013). Trajectories of attentional development: an exploration with the master activation map model. *Dev Psychol, 49*(4), 615-631. doi:10.1037/a0028410

Milham, M. P., Erickson, K. I., Banich, M. T., Kramer, A. F., Webb, A., Wszalek, T., & Cohen, N. J. (2002). Attentional control in the aging brain: insights from an fMRI study of the stroop task. *Brain and cognition, 49*(3), 277-296. doi:10.1006/brcg.2001.1501

Milliken, B., Lupianez, J., Roberts, M., & Stevanovski, B. (2003). Orienting in space and time: joint contributions to exogenous spatial cuing effects. *Psychon Bull Rev, 10*(4), 877-883. doi:10.3758/bf03196547

Mizzi, R., & Michael, G. A. (2014). The role of the collicular pathway in the salience-based progression of visual attention. *Behav Brain Res, 270*, 330-338. doi:10.1016/j.bbr.2014.05.043

Moher, J., & Egeth, H. E. (2012). The ignoring paradox: cueing distractor features leads first to selection, then to inhibition of to-be-ignored items. *Atten Percept Psychophys, 74*(8), 1590-1605. doi:10.3758/s13414-012-0358-0

Moher, J., Lakshmanan, B. M., Egeth, H. E., & Ewen, J. B. (2014). Inhibition drives early feature-based attention. *Psychol Sci, 25*(2), 315-324. doi:10.1177/0956797613511257

Mojsilovic, A. (2005). A computational model for color naming and describing color composition of images. *IEEE Trans Image Process, 14*(5), 690-699. doi:10.1109/tip.2004.841201

Motter, B. C. (1994). Neural correlates of attentive selection for color or luminance in extrastriate area V4. *J Neurosci, 14*(4), 2178-2189. doi:10.1523/JNEUROSCI.14-04-02178.1994

Mounts, J. R. (2000). Attentional capture by abrupt onsets and feature singletons produces inhibitory surrounds. *Percept Psychophys, 62*(7), 1485-1493. doi:10.3758/bf03212148

Muller, H. J., & Findlay, J. M. (1988). The effect of visual attention on peripheral discrimination thresholds in single and multiple element displays. *Acta Psychol (Amst), 69*(2), 129-155. doi:10.1016/0001-6918(88)90003-0

Müller-Oehring, E. M., Schulte, T., Rohlfing, T., Pfefferbaum, A., & Sullivan, E. V. (2013). Visual search and the aging brain: discerning the effects of age-related brain volume shrinkage on alertness, feature binding, and attentional control. *Neuropsychology, 27*(1), 48. doi:10.1037/a0030921

Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing Cognitive Control: Three Key Transitions. *Curr Dir Psychol Sci, 21*(2), 71-77. doi:10.1177/0963721412436807

Munneke, J., Heslenfeld, D. J., Usrey, W. M., Theeuwes, J., & Mangun, G. R. (2011). Preparatory effects of distractor suppression: evidence from visual cortex. *PloS one, 6*(12), e27700. doi:10.1371/journal.pone.0027700

Nelson, T. O. (1990). Metamemory: A theoretical framework and new findings. In *Psychology of learning and motivation* (Vol. 26, pp. 125-173): Elsevier.

Niebaum, J. C., Chevalier, N., Guild, R. M., & Munakata, Y. (2019). Adaptive control and the avoidance of cognitive control demands across development. *Neuropsychologia, 123*, 152-158. doi:10.1016/j.neuropsychologia.2018.04.029

Noonan, M. P., Adamian, N., Pike, A., Printzlau, F., Crittenden, B. M., & Stokes, M. G. (2016). Distinct Mechanisms for Distractor Suppression and Target Facilitation. *J Neurosci, 36*(6), 1797-1807. doi:10.1523/JNEUROSCI.2133-15.2016

Nothdurft, H. (2000). Salience from feature contrast: additivity across dimensions. *Vision Res, 40*(10-12), 1183-1201. doi:10.1016/s0042-6989(00)00031-6

Nothdurft, H. C. (1993). The role of features in preattentive vision: comparison of orientation, motion and color cues. *Vision Res, 33*(14), 1937-1958. doi:10.1016/0042-6989(93)90020-w

Olivers, C. N., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in Cognitive Sciences, 15*(7), 327-334. doi:10.1016/j.tics.2011.05.004

Osborne, J. W. (2006). Power analysis for multivariate and repeated measurements designs via SPSS: correction and extension of D'Amico, Neilands, and Zambarano (2001). *Behav Res Methods, 38*(2), 353-354. doi:10.3758/bf03192787

Paxton, J. L., Barch, D. M., Racine, C. A., & Braver, T. S. (2008). Cognitive control, goal maintenance, and prefrontal function in healthy aging. *Cereb Cortex, 18*(5), 1010-1028. doi:10.1093/cercor/bhm135

Pearson, D. A., & Lane, D. M. (1990). Visual attention movements: a developmental study. *Child Dev, 61*(6), 1779-1795. doi:10.1111/j.1467-8624.1990.tb03565.x

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., . . . Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior research methods, 51*(1), 195-203. doi:10.3758/s13428-018-01193-y

Peirce, J. W. (2008). Generating Stimuli for Neuroscience Using PsychoPy. *Front Neuroinform, 2*, 10. doi:10.3389/neuro.11.010.2008

Pelli, D. G., & Zhang, L. (1991). Accurate control of contrast on microcomputer displays. *Vision Res, 31*(7-8), 1337-1350. doi:10.1016/0042-6989(91)90055-a

Pestilli, F., Carrasco, M., Heeger, D. J., & Gardner, J. L. (2011). Attentional enhancement via selection and pooling of early sensory responses in human visual cortex. *Neuron, 72*(5), 832-846. doi:10.1016/j.neuron.2011.09.025

Pfister, R., & Janczyk, M. (2013). Confidence intervals for two sample means: Calculation, interpretation, and a few simple rules. *Adv Cogn Psychol, 9*(2), 74-80. doi:10.2478/v10053-008-0133-x

Pilling, M., Wiggett, A., Özgen, E., & Davies, I. R. (2003). Is color “categorical perception” really perceptual? *Memory & Cognition, 31*(4), 538-551. doi:10.3758/BF03196095

Posner, M. I. (1980). Orienting of attention. *Q J Exp Psychol, 32*(1), 3-25. doi:10.1080/00335558008248231

Posner, M. I. (1988). *Structures and function of selective attention*: American Psychological Association.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. *Attention and performance X: Control of language processes, 32*, 531-556.

Pratt, J., & Bellomo, C. N. (1999). Attentional capture in younger and older adults. *Aging, Neuropsychology, and Cognition, 6*(1), 19-31. doi:10.1076/anec.6.1.19.792

Pratte, M.S., Rouder, J.N., Morey, R.D. & Feng, C. (2010). Exploring the differences in distributional properties between Stroop and Simon effects using delta plots. *Attention, Perception, & Psychophysics*, *72*(7), 2013–2025. doi:10.3758/APP.72.7.2013

Proctor, R. W., Lu, C. H., & Van Zandt, T. (1992). Enhancement of the Simon effect by response precuing. *Acta psychologica*, *81*(1), 53–74. doi:10.1016/0001-6918(92)90011-2

Redick, T. S. (2014). Cognitive control in context: working memory capacity and proactive control. *Acta Psychol (Amst), 145*, 1-9. doi:10.1016/j.actpsy.2013.10.010

Redick, T. S., Calvo, A., Gay, C. E., & Engle, R. W. (2011). Working memory capacity and go/no-go task performance: selective effects of updating, maintenance, and inhibition. *J Exp Psychol Learn Mem Cogn, 37*(2), 308-324. doi:10.1037/a0022216

Reuter-Lorenz, P. A., Jonides, J., Smith, E. E., Hartley, A., Miller, A., Marshuetz, C., & Koeppe, R. A. (2000). Age differences in the frontal lateralization of verbal and spatial working memory revealed by PET. *J Cogn Neurosci, 12*(1), 174-187. doi:10.1162/089892900561814

Ridderinkhof, K. R., & van der Stelt, O. (2000). Attention and selection in the growing child: views derived from developmental psychophysiology. *Biol Psychol, 54*(1-3), 55-106. doi:10.1016/s0301-0511(00)00053-3

Riddoch, M. J., Chechlacz, M., Mevorach, C., Mavritsaki, E., Allen, H., & Humphreys, G. W. (2010). The neural mechanisms of visual selection: the view from neuropsychology. *Ann N Y Acad Sci, 1191*, 156-181. doi:10.1111/j.1749-6632.2010.05448.x

Ristic, J., & Kingstone, A. (2012). A new form of human spatial attention: Automated symbolic orienting. *Visual Cognition, 20*(3), 244-264. doi:10.1080/13506285.2012.658101

Rodrigues, P. F., & Pandeirada, J. N. (2018). When visual stimulation of the surrounding environment affects children’s cognitive performance. *Journal of experimental child psychology, 176*, 140-149. doi:10.1016/j.jecp.2018.07.014

Rodrigues, P. F. S., & Pandeirada, J. N. S. (2018). When visual stimulation of the surrounding environment affects children's cognitive performance. *J Exp Child Psychol, 176*, 140-149. doi:10.1016/j.jecp.2018.07.014

Roque, N. A., Wright, T. J., & Boot, W. R. (2016). Do different attention capture paradigms measure different types of capture? *Attention, Perception, & Psychophysics, 78*(7), 2014-2030. doi:10.3758/s13414-016-1117-4

Rosen, A. C., Rao, S. M., Caffarra, P., Scaglioni, A., Bobholz, J. A., Woodley, S. J., . . . Binder, J. R. (1999). Neural basis of endogenous and exogenous spatial orienting. A functional MRI study. *J Cogn Neurosci, 11*(2), 135-152. doi:10.1162/089892999563283

Rosenthal, R., Cooper, H., & Hedges, L. (1994). Parametric measures of effect size. In H. Cooper & L. V. Hedges (Eds.), *The handbook of research synthesis* (Vol. 621, pp. 231-244): Russell Sage Foundation.

Rosvold, H. E., Mirsky, A. F., Sarason, I., Bransome Jr, E. D., & Beck, L. H. (1956). A continuous performance test of brain damage. *Journal of consulting psychology, 20*(5), 343. doi:10.1037/h0043220

Rush, B. K., Barch, D. M., & Braver, T. S. (2006). Accounting for cognitive aging: context processing, inhibition or processing speed? *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn, 13*(3-4), 588-610. doi:10.1080/13825580600680703

Ruz, M., & Lupiáñez, J. (2002). A review of attentional capture: On its automaticity and sensitivity to endogenous control. *Psicológica, 23*(2).

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology: General, 132*(4), 566. doi:10.1037/0096-3445.132.4.566

Sawaki, R., & Luck, S. J. (2010). Capture versus suppression of attention by salient singletons: electrophysiological evidence for an automatic attend-to-me signal. *Atten Percept Psychophys, 72*(6), 1455-1470. doi:10.3758/APP.72.6.1455

Sawaki, R., & Luck, S. J. (2013). Active suppression after involuntary capture of attention. *Psychon Bull Rev, 20*(2), 296-301. doi:10.3758/s13423-012-0353-4

Sawaki, R., & Luck, S. J. (2014). How the brain prevents and terminates shifts of attention. In G. R. Mangun (Ed.), *Cognitive electrophysiology of attention: Signals of the mind* (pp. 16-29): Elsevier.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime reference guide*: Psychology Software Tools, Incorporated.

Schul, R., Townsend, J., & Stiles, J. (2003). The development of attentional orienting during the school-age years. *Developmental Science, 6*(3), 262-272. doi:10.1111/1467-7687.00282

Serences, J. T., & Yantis, S. (2006). Selective visual attention and perceptual coherence. *Trends Cogn Sci, 10*(1), 38-45. doi:10.1016/j.tics.2005.11.008

Serences, J. T., Yantis, S., Culberson, A., & Awh, E. (2004). Preparatory activity in visual cortex indexes distractor suppression during covert spatial orienting. *J Neurophysiol, 92*(6), 3538-3545. doi:10.1152/jn.00435.2004

Shepherd, M., & Muller, H. J. (1989). Movement versus focusing of visual attention. *Percept Psychophys, 46*(2), 146-154. doi:10.3758/bf03204974

Shimi, A., Nobre, A. C., Astle, D., & Scerif, G. (2014). Orienting attention within visual short-term memory: development and mechanisms. *Child Dev, 85*(2), 578-592. doi:10.1111/cdev.12150

Shimi, A., Nobre, A. C., & Scerif, G. (2015). ERP markers of target selection discriminate children with high vs. low working memory capacity. *Front Syst Neurosci, 9*, 153. doi:10.3389/fnsys.2015.00153

Shomstein, S., & Gottlieb, J. (2016). Spatial and non-spatial aspects of visual attention: Interactive cognitive mechanisms and neural underpinnings. *Neuropsychologia, 92*, 9-19. doi:10.1016/j.neuropsychologia.2016.05.021

Smith, T., & Guild, J. (1931). The CIE colorimetric standards and their use. *Transactions of the optical society*, *33*(3), 73-134.

Smith, J. D., Shields, W. E., & Washburn, D. A. (2003). The comparative psychology of uncertainty monitoring and metacognition. *Behav Brain Sci, 26*(3), 317-339; discussion 340-373. doi:10.1017/s0140525x03000086

Sobel, K. V., Pickard, M. D., & Acklin, W. T. (2009). Using feature preview to investigate the roles of top–down and bottom–up processing in conjunction search. *Acta Psychologica, 132*(1), 22-30. doi:10.1016/j.actpsy.2009.06.003

Soto, D., Heinke, D., Humphreys, G. W., & Blanco, M. J. (2005). Early, involuntary top-down guidance of attention from working memory. *J Exp Psychol Hum Percept Perform, 31*(2), 248-261. doi:10.1037/0096-1523.31.2.248

Soto, D., Hodsoll, J., Rotshtein, P., & Humphreys, G. W. (2008). Automatic guidance of attention from working memory. *Trends Cogn Sci, 12*(9), 342-348. doi:10.1016/j.tics.2008.05.007

Soto, D., & Humphreys, G. W. (2007). Automatic guidance of visual attention from verbal working memory. *J Exp Psychol Hum Percept Perform, 33*(3), 730-737. doi:10.1037/0096-1523.33.3.730

Soto, D., & Humphreys, G. W. (2009). Automatic selection of irrelevant object features through working memory: Evidence for top-down attentional capture. *Experimental Psychology, 56*(3), 165-172. doi:10.1027/1618-3169.56.3.165

Soto, D., Humphreys, G. W., & Rotshtein, P. (2007). Dissociating the neural mechanisms of memory-based guidance of visual selection. *Proc Natl Acad Sci U S A, 104*(43), 17186-17191. doi:10.1073/pnas.0703706104

Steele, A., Karmiloff-Smith, A., Cornish, K., & Scerif, G. (2012). The multiple subfunctions of attention: differential developmental gateways to literacy and numeracy. *Child Dev, 83*(6), 2028-2041. doi:10.1111/j.1467-8624.2012.01809.x

Stormer, V. S., Alvarez, G. A., & Cavanagh, P. (2014). Within-hemifield competition in early visual areas limits the ability to track multiple objects with attention. *J Neurosci, 34*(35), 11526-11533. doi:10.1523/JNEUROSCI.0980-14.2014

Strasburger, H. (2001). Converting between measures of slope of the psychometric function. *Perception & Psychophysics, 63*(8), 1348-1355. doi:10.3758/BF03194547

Sundberg, K. A., Mitchell, J. F., & Reynolds, J. H. (2009). Spatial attention modulates center-surround interactions in macaque visual area v4. *Neuron, 61*(6), 952-963. doi:10.1016/j.neuron.2009.02.023

Tamura, S., & Sato, K. (2020). Age-related changes in visual search: manipulation of colour cues based on cone contrast and opponent modulation space. *Sci Rep, 10*(1), 21328. doi:10.1038/s41598-020-78303-4

The GIMP Development Team. (2019). GIMP. Retrieved from https://www.gimp.org

Theeuwes, J. (1991). Cross-dimensional perceptual selectivity. *Percept Psychophys, 50*(2), 184-193. doi:10.3758/bf03212219

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Percept Psychophys, 51*(6), 599-606. doi:10.3758/bf03211656

Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture. *Psychon Bull Rev, 11*(1), 65-70. doi:10.3758/bf03206462

Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychol (Amst), 135*(2), 77-99. doi:10.1016/j.actpsy.2010.02.006

Theeuwes, J. (2013). Feature-based attention: It is all bottom-up priming. *Philosophical Transactions of the Royal Society B: Biological Sciences, 368*(1628), 20130055. doi:10.1098/rstb.2013.0055

Theeuwes, J., Kramer, A. F., & Belopolsky, A. V. (2004). Attentional set interacts with perceptual load in visual search. *Psychon Bull Rev, 11*(4), 697-702. doi:10.3758/bf03196622

Theeuwes, J., Reimann, B., & Mortier, K. (2006). Visual search for featural singletons: No top-down modulation, only bottom-up priming. *Visual Cognition, 14*(4-8), 466-489. doi:10.1080/13506280500195110

Theeuwes, J., & van der Burg, E. (2008). The role of cueing in attentional capture. *Visual Cognition, 16*(2-3), 232-247. doi:10.1080/13506280701462525

Theeuwes, J., & Van der Burg, E. (2011). On the limits of top-down control of visual selection. *Atten Percept Psychophys, 73*(7), 2092-2103. doi:10.3758/s13414-011-0176-9

Trafimow, D., Amrhein, V., Areshenkoff, C. N., Barrera-Causil, C. J., Beh, E. J., Bilgic, Y. K., . . . Marmolejo-Ramos, F. (2018). Manipulating the Alpha Level Cannot Cure Significance Testing. *Front Psychol, 9*, 699. doi:10.3389/fpsyg.2018.00699

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: evidence from search asymmetries. *Psychol Rev, 95*(1), 15-48. doi:10.1037/0033-295x.95.1.15

Treisman, A., & Sato, S. (1990). Conjunction search revisited. *J Exp Psychol Hum Percept Perform, 16*(3), 459-478. doi:10.1037//0096-1523.16.3.459

Treisman, A., & Souther, J. (1985). Search asymmetry: a diagnostic for preattentive processing of separable features. *J Exp Psychol Gen, 114*(3), 285-310. doi:10.1037//0096-3445.114.3.285

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cogn Psychol, 12*(1), 97-136. doi:10.1016/0010-0285(80)90005-5

Troller-Renfree, S. V., Buzzell, G. A., & Fox, N. A. (2020). Changes in working memory influence the transition from reactive to proactive cognitive control during childhood. *Dev Sci, 23*(6), e12959. doi:10.1111/desc.12959

Tsotsos, J. K. (1995). Toward a computational model of visual attention. In T. V. Papathomas, C. Chubb, A. Gorea, & E. Kowler (Eds.), *Early vision and beyond* (pp. 207-218): The MIT Press.

Tsvetanov, K. A., Mevorach, C., Allen, H., & Humphreys, G. W. (2013). Age-related differences in selection by visual saliency. *Atten Percept Psychophys, 75*(7), 1382-1394. doi:10.3758/s13414-013-0499-9

Tsvetanov, K. A., Mevorach, C., Allen, H., & Humphreys, G. W. (2013). Age-related differences in selection by visual saliency. *Atten Percept Psychophys, 75*(7), 1382-1394. doi:10.3758/s13414-013-0499-9

Umiltà, C., & Liotti, M. (1987). Egocentric and relative spatial codes in SR compatibility. *Psychol Res*, *49*(2), 81-90. doi:10.1007/BF00308672

Van der Stigchel, S., Belopolsky, A. V., Peters, J. C., Wijnen, J. G., Meeter, M., & Theeuwes, J. (2009). The limits of top-down control of visual attention. *Acta Psychol (Amst), 132*(3), 201-212. doi:10.1016/j.actpsy.2009.07.001

Van der Stigchel, S., Meeter, M., & Theeuwes, J. (2007). Top-down influences make saccades deviate away: The case of endogenous cues. *Acta Psychologica, 125*(3), 279-290. doi:10.1016/j.actpsy.2006.08.002

Van Gerven, P. W., Hurks, P. P., Bovend'Eerdt, T. J., & Adam, J. J. (2016). Switch hands! Mapping proactive and reactive cognitive control across the life span. *Dev Psychol, 52*(6), 960-971. doi:10.1037/dev0000116

van Zoest, W., Donk, M., & Theeuwes, J. (2004). The role of stimulus-driven and goal-driven control in saccadic visual selection. *J Exp Psychol Hum Percept Perform, 30*(4), 746-759. doi:10.1037/0096-1523.30.4.749

Vecera, S. P., Cosman, J. D., Vatterott, D. B., & Roper, Z. J. J. (2014). The Control of Visual Attention: Toward a Unified Account. In B. H. Ross (Ed.), *Psychology of learning and motivation* (Vol. 60, pp. 303-347): Elsevier.

Velanova, K., Lustig, C., Jacoby, L. L., & Buckner, R. L. (2007). Evidence for frontally mediated controlled processing differences in older adults. *Cereb Cortex, 17*(5), 1033-1046. doi:10.1093/cercor/bhl013

Verfaellie, M., Bowers, D., & Heilman, K. M. (1988). Attentional factors in the occurrence of stimulus-response compatibility effects. *Neuropsychologia*, *26*(3), 435-444. doi:10.1016/0028-3932(88)90096-6

Vogel, E. K., & Machizawa, M. G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature, 428*(6984), 748-751. doi:10.1038/nature02447

Vogel, E. K., McCollough, A. W., & Machizawa, M. G. (2005). Neural measures reveal individual differences in controlling access to working memory. *Nature, 438*(7067), 500-503. doi:10.1038/nature04171

Wainwright, A., & Bryson, S. E. (2002). The development of exogenous orienting: mechanisms of control. *J Exp Child Psychol, 82*(2), 141-155. doi:10.1016/s0022-0965(02)00002-4

Wainwright, A., & Bryson, S. E. (2005). The development of endogenous orienting: control over the scope of attention and lateral asymmetries. *Dev Neuropsychol, 27*(2), 237-255. doi:10.1207/s15326942dn2702_3

Walter, S., Quigley, C., & Mueller, M. M. (2014). Competitive interactions of attentional resources in early visual cortex during sustained visuospatial attention within or between visual hemifields: Evidence for the different-hemifield advantage. *Journal of Cognitive Neuroscience, 26*(5), 938-954. doi:10.1162/jocn_a_00547

Wang, B., & Theeuwes, J. (2018). How to inhibit a distractor location? Statistical learning versus active, top-down suppression. *Attention, Perception, & Psychophysics, 80*(4), 860-870. doi:10.3758/s13414-018-1493-z

Wang, B., van Driel, J., Ort, E., & Theeuwes, J. (2019). Anticipatory Distractor Suppression Elicited by Statistical Regularities in Visual Search. *J Cogn Neurosci, 31*(10), 1535-1548. doi:10.1162/jocn_a_01433

Weaver, M. D., Paoletti, D., & van Zoest, W. (2014). The impact of predictive cues and visual working memory on dynamic oculomotor selection. *J Vis, 14*(3), 27. doi:10.1167/14.3.27

West, R. (2000). In defense of the frontal lobe hypothesis of cognitive aging. *J Int Neuropsychol Soc, 6*(6), 727-729; discussion 730. doi:10.1017/s1355617700666109

Wolfe, J. M. (2014). Approaches to visual search: Feature integration theory and guided search. *The Oxford handbook of attention, 11*, 35-44.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: an alternative to the feature integration model for visual search. *J Exp Psychol Hum Percept Perform, 15*(3), 419-433. doi:10.1037//0096-1523.15.3.419

Won, B.-Y., & Jiang, Y. V. (2015). Spatial working memory interferes with explicit, but not probabilistic cuing of spatial attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41*(3), 787. doi:10.1037/xlm0000040

Won, B. Y., Forloines, M., Zhou, Z., & Geng, J. J. (2020). Changes in visual cortical processing attenuate singleton distraction during visual search. *cortex, 132*, 309-321. doi:10.1016/j.cortex.2020.08.025

Wong-Kee-You, A. M. B., Tsotsos, J. K., & Adler, S. A. (2019). Development of spatial suppression surrounding the focus of visual attention. *J Vis, 19*(7), 9. doi:10.1167/19.7.9

Woodman, G. F., Carlisle, N. B., & Reinhart, R. M. (2013). Where do we store the memory representations that guide attention? *Journal of Vision, 13*(3), 1-1. doi:10.1167/13.3.1

Woodman, G. F., & Luck, S. J. (2007). Do the contents of visual working memory automatically influence attentional selection during visual search? *J Exp Psychol Hum Percept Perform, 33*(2), 363-377. doi:10.1037/0096-1523.33.2.363

Wuerger, S. (2013). Colour constancy across the life span: evidence for compensatory mechanisms. *PloS one, 8*(5), e63921. doi:10.1371/journal.pone.0063921

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: voluntary versus automatic allocation. *J Exp Psychol Hum Percept Perform, 16*(1), 121-134. doi:10.1037//0096-1523.16.1.121

Yeh, S. L., & Liao, H. I. (2008). On the generality of the contingent orienting hypothesis. *Acta Psychol (Amst), 129*(1), 157-165. doi:10.1016/j.actpsy.2008.05.008

Yen, S. C., & Finkel, L. H. (1998). Extraction of perceptually salient contours by striate cortical networks. *Vision Res, 38*(5), 719-741. doi:10.1016/s0042-6989(97)00197-1

Zanto, T. P., Hennigan, K., Östberg, M., Clapp, W. C., & Gazzaley, A. (2010). Predictive knowledge of stimulus relevance does not influence top-down suppression of irrelevant information in older adults. *cortex, 46*(4), 564-574. doi:10.1016/j.cortex.2009.08.003

Zhuang, X., & Papathomas, T. V. (2011). Cue relevance effects in conjunctive visual search: cueing for location, color, and orientation. *J Vis, 11*(7), 6-6. doi:10.1167/11.7.6

Appendix

Appendix 3.1. The Influence of Singleton Presence on Cue-Utilisation

To understand whether the presence of the singleton distracter influenced cue-utilisation, separate 3 (Block Predictiveness: Mostly Predictive, Low Predictive, Baseline) x 2 (Singleton Presence) x 3 (Age-Group) mixed ANOVAs were conducted on average cueing ratios for response time and accuracy data. If singleton-presence influences cue-utilisation, it was expected that participants would have greater cueing ratios on singleton-present trials (vs singleton-absent trials) in the Mostly Predictive block, relative to the Baseline block. This pattern of results was predicted to occur in nine- to 11-year-olds and adults who are expected to have developed a form of endogenous control.

Response Time

The Block x Singleton-Presence x Age-Group interaction was not significant ($F(4, 252) = .64$, $p = .636$, $\eta_p^2 = .01$; *see Figure 3.1.1 overleaf*). As shown previously, the Block x Age-Group interaction ($F(4, 252) = 15.79$, $p < .001$, $\eta_p^2 = .20$), the main effects of Block ($F(1.65, 207.22) = 82.15$, $p < .001$, $\eta_p^2 = .40$) and Age-Group ($F(2, 126) = 16.76$, $p < .001$, $\eta_p^2 = .21$) were all significant and interpreted in Chapter 3. The remaining main effect and interactions were non-significant (*see Table 3.1.1*).

Table 3.1.1. F-statistics for the remaining main effect and interactions which did not meet significance in the Block x Singleton-Presence x Age-Group mixed ANOVA on average cueing ratios for response times.

	$F(df_1, df_2)$ = statistic	p	η_p^2
Singleton Presence	$F(1, 126) = 3.29$	.072	.03
Singleton Presence x Age-Group	$F(2, 126) = .06$	.946	.001
Block x Singleton Presence	$F(2, 252) = .81$	.447	.01

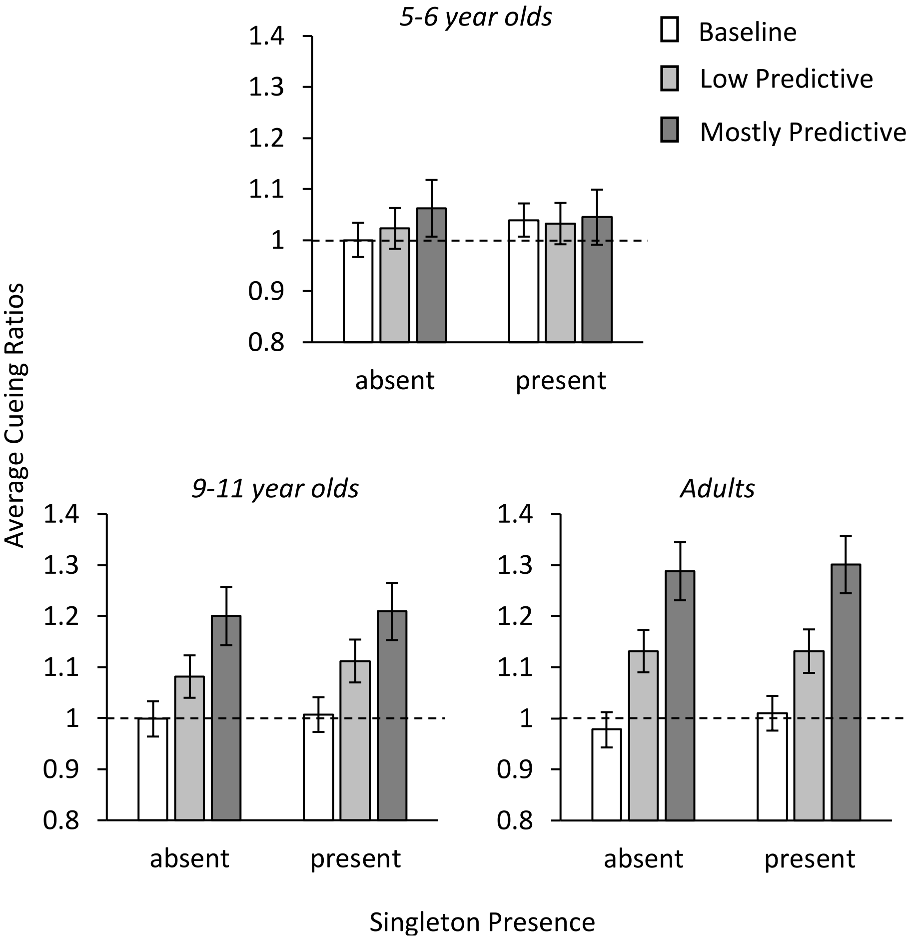

Figure 3.1.1. Average cueing ratios on singleton-absent and singleton-present trials in the Baseline block (white bars), Low Predictive block (light grey bars) and Mostly Predictive block (dark grey bars) for three age-groups. Error bars represent 95% confidence intervals.

Accuracy

The results show that the Block x Singleton-Presence x Age-Group interaction failed to meet significance ($F(4, 252) = .75$, $p = .559$, $\eta_p^2 = .01$; *see Table 3.1.2 overleaf*). The main effect of Block was significant ($F(1.54, 193.39) = 11.13$, $p < .001$, $\eta_p^2 = .08$) and reported in Chapter 3. Remaining main effects and interactions were non-significant (*see Table 3.1.3 overleaf*).

Table 3.1.2. Average cueing ratios (standard error [confidence intervals]) for accuracy data on singleton-absent and singleton-present trials across block conditions and age-groups.

		5- to 6-year-olds	*9- to 11-year-olds*	*Adults*
Mostly Predictive block	*Absent*	1.02 (.02 [.99, 1.05])	1.05 (.02 [1.02, 1.09])	1.03 (.02 [1.00, 1.06])
	Present	1.01 (.01 [.99, 1.03])	1.03 (.01 [1.01, 1.05])	1.01 (.01 [.99, 1.03])
Low Predictive block	*Absent*	1.00 (.01 [.99, 1.02])	1.00 (.01 [.99, 1.02])	1.01 (.01 [1.00, 1.02])
	Present	1.00 (.01 [.98, 1.02])	1.01 (.01 [1.00, 1.03])	1.00 (.01 [.98, 1.01])
Baseline block	*Absent*	1.00 (.01 [.98, 1.01])	.98 (.01 [.97, 1.00])	1.00 (.01 [.98, 1.01])
	Present	.99 (.01 [.98, 1.01])	1.00 (.01 [.99, 1.02])	1.00 (.01 [.98, 1.02)

Note: Absent = singleton-absent; Present = singleton-present

Table 3.1.3. F-statistics for the remaining main effect and interactions which did not meet significance in the Block x Singleton-Presence x Age-Group mixed ANOVA on average cueing ratios for accuracy.

	$F(\mathrm{df}_1, \mathrm{df}_2)$ = statistic	*p*	η_p^2
Age-Group	*F*(2, 126) = 1.19	.307	.02
Singleton-Presence	*F*(1, 126) = .51	.475	.004
Block x Age-Group	*F*(4, 252) = .85	.498	.01
Singleton-Presence x Age-Group	*F*(2, 126) = .75	.477	.01
Block x Singleton-Presence	*F*(2, 252) = 2.19	.114	.02

Overall, the findings from response time and accuracy data suggest that participants did not utilise the cues more when the singleton distracter was present in the display, relative to absent, across Block conditions. Therefore, cue-utilisation performance was not influenced by singleton-presence across all age-groups.

Appendix 3.2. Four-Way Mixed ANOVA on Cue-Utilisation and Attentional Capture

As described in the pre-registration (osf.io/cvj8p) for the hypothesis assessing attentional capture, I conducted a four-way Age-Group x Cue Validity (valid, invalid) x Singleton-Presence (absent, present) x Block (Mostly Predictive, Low Predictive, Baseline) mixed ANOVA on untransformed median response times and mean accuracy. If endogenous cue-utilisation reduced attentional capture, I expected to find a four-way interaction. This would show improved performance (faster response times, better accuracy) on valid trials in the Mostly Predictive block when a singleton distracter was present in the display, relative to the Baseline block. It was predicted that adults would show this pattern of results but it was questionable whether children, specifically nine- to 11-year-olds, would behave similarly.

Response Time

The four-way Block x Cue Validity x Singleton-Presence x Age-Group interaction was not significant ($F(4, 252) = .59$, $p = .672$, $\eta_p^2 = .01$; *see Table 3.2.1*). Main effects of Cue Validity ($F(1, 126) = 73.59$, $p < .001$, $\eta_p^2 = .37$), Singleton-Presence ($F(1, 126) = 90.74$, $p < .001$, $\eta_p^2 = .42$) and Age-Group ($F(1, 126) = 157.92$, $p < .001$, $\eta_p^2 = .72$) were found. The Singleton-Presence x Age-Group ($F(2, 126) = 8.42$, $p < .001$, $\eta_p^2 = .12$) interaction was significant and showed that all age-groups were slower on singleton-present trials compared to singleton-absent trials (all *ps* < .015). Response times on singleton-absent and singleton-present trials were slowest for five- to six-year-olds, followed by nine- to 11-year-olds and finally adults (*5-6 years < 9-11 years < adults; all ps < .001*). The interaction terms Cue Validity x Age-Group ($F(2, 126) = 3.75$, $p = .026$, $\eta_p^2 = .06$), and Block x Cue Validity ($F(1.79, 225.20) = 33.17$, $p < .001$, $\eta_p^2 = .21$) met significance. The three-way Block x Cue Validity x Age-Group interaction ($F(3.58, 225.20) = 4.06$, $p = .005$, $\eta_p^2 = .06$) was also significant. This showed that all age-groups were faster on valid trials relative to invalid trials in the Mostly Predictive block (*all ps* < .006), but this difference was not significant in the Baseline block (*all ps* > .10). In the Low Predictive block, nine-to 11-year-olds and adults were faster on valid trials relative to invalid trials (*both ps* < .001), but this difference was not significant in five- to six-year-olds (*p* = .279). For all age-groups, comparisons between block conditions showed that response times on valid trials as well as invalid trials did not significantly differ between blocks (*all ps* > .08). Age-group comparisons showed that response times for valid trials and invalid trials in all block conditions significantly differed between all age-groups (*all ps* < .001). Specifically, five- to six-year-olds were slower, relative to nine- to 11-year-olds and adults, as well as between nine- to 11-year-olds and adults. These differences are suggestive of age-related slowing of response times between age-groups. All other main effects and interactions were not significant.

Accuracy

The predicted four-way Block x Cue Validity x Singleton-Presence x Age-Group interaction was not significant (*F*(4, 252) = .54, *p* = .709, η_p^2 = .01; (*see Table 3.2.2*). Main effects of Block (*F*(1.83, 230.12) = 6.65, *p* = .002, η_p^2 = .05) and Cue Validity (*F*(1, 126) = 7.95, *p* = .006, η_p^2 = .06) were found. The two-way Block x Cue Validity interaction (*F*(1.74, 218.60) = 12.31, *p* < .001, η_p^2 = .09) was significant. This showed that within blocks, mean accuracy was significantly higher on valid trials relative to invalid trials in the Mostly Predictive block (*p* < .001), but not in the Low Predictive block (*p* = .315) and Baseline block (*p* = .058). Between blocks, mean accuracy on invalid trials was lower in the Mostly Predictive block relative to the Low Predictive block (*p* = .002) and the Baseline block (*p* < .001). There was no significant difference between the Low Predictive and Baseline blocks on invalid trials (*p* = .492). On valid trials, mean accuracy did not differ across all block conditions (*all ps* > .60). All other main effects and interactions were not significant.

Table 3.2.1. Average median response times (s), standard error and 95% confidence intervals from the mean across block, cue validity and singleton-presence variables.

			5- to 6-year-olds			*9- to 11-year-olds*			*Adults*		
			M	*SE*	*95% CI*	*M*	*SE*	*95% CI*	*M*	*SE*	*95% CI*
Mostly Predictive block	*Valid*	*Absent*	1.54	.04	1.46, 1.63	.87	.05	.78, .96	.58	.05	.49, .67
		Present	1.66	.05	1.55, 1.76	.92	.05	.82, 1.02	.60	.05	.49, .70
	Invalid	*Absent*	1.63	.05	1.52, 1.73	1.04	.06	.93, 1.15	.74	.06	.63, .85
		Present	1.71	.06	1.60, 1.82	1.11	.06	1.00, 1.22	.78	.06	.66, .89
Low Predictive block	*Valid*	*Absent*	1.57	.05	1.47, 1.66	.92	.05	.83, 1.02	.59	.05	.50, .69
		Present	1.70	.05	1.60, 1.81	.98	.05	.87, 1.09	.63	.05	.52, .73
	Invalid	*Absent*	1.57	.05	1.48, 1.66	.99	.05	.89, 1.08	.67	.05	.58, .77
		Present	1.73	.05	1.63, 1.84	1.08	.05	.97, 1.18	.71	.05	.60, .81
Baseline block	*Valid*	*Absent*	1.63	.05	1.53, 1.73	.92	.06	.82, 1.03	.63	.06	.52, .74
		Present	1.67	.05	1.57, 1.77	1.00	.05	.90, 1.11	.65	.05	.55, .75
	Invalid	*Absent*	1.63	.06	1.51, 1.75	.92	.06	.80, 1.05	.61	.06	.49, .74
		Present	1.72	.06	1.62, 1.83	1.01	.06	.90, 1.12	.66	.06	.54, .77

Note: M – mean; SE – standard error of mean; CI – 95% confidence intervals from the mean (lower bound, upper bound).

Table 3.2.2. Mean accuracy, standard error and 95% confidence intervals from the mean across block, cue validity and singleton-presence variables.

			5- to 6-year-olds			*9- to 11-year-olds*			*Adults*		
			M	*SE*	*95% CI*	*M*	*SE*	*95% CI*	*M*	*SE*	*95% CI*
Mostly Predictive block	*Valid*	*Absent*	.96	.01	.95, .97	.96	.01	.95, .98	.98	.01	.96, .99
		Present	.96	.01	.94, .97	.96	.01	.95, .97	.97	.01	.96, .99
	Invalid	*Absent*	.95	.01	.92, .97	.93	.01	.91, .95	.95	.01	.93, .97
		Present	.95	.01	.93, .97	.94	.01	.92, .96	.96	.01	.94, .98
Low Predictive block	*Valid*	*Absent*	.97	.01	.96, .98	.97	.01	.95, .98	.98	.01	.96, .99
		Present	.96	.01	.95, .97	.97	.01	.95, .98	.97	.01	.95, .98
	Invalid	*Absent*	.97	.01	.96, .98	.97	.01	.95, .98	.97	.01	.96, .98
		Present	.96	.01	.95, .98	.96	.01	.95, .97	.97	.01	.96, .98
Baseline block	*Valid*	*Absent*	.96	.01	.95, .97	.96	.01	.95, .97	.97	.01	.96, .98
		Present	.96	.01	.95, .97	.96	.01	.95, .98	.97	.01	.96, .98
	Invalid	*Absent*	.96	.01	.95, .98	.98	.01	.97, .99	.97	.01	.96, .99
		Present	.97	.01	.96, .98	.96	.01	.95, .97	.97	.01	.96, .98

Note: M – mean; SE – standard error of mean; CI – 95% confidence intervals from the mean (lower bound, upper bound).

Appendix 3.3. The Influence of Block Order on Cue-Utilisation and Attentional Capture

This study used a mixed design which asked all participants in each age-group to complete all three block conditions. Order of the block conditions was counterbalanced for each age-group (with the exception of a small discrepancy in five- to six-year-olds[37]). I considered the influence of order on cue-utilisation and attentional capture in separate analyses on response times.

Cue-Utilisation

If the order which participants completed the block conditions influenced cue-utilisation, it is expected that orders which first presented blocks that discouraged cue-use (Baseline & Low Predictive) would lead to reduced cue-utilisation in later blocks than orders which first presented the block which encouraged cue-use (Mostly Predictive). We will assess if this pattern of results was shown in all age-groups. Separate Block (3 levels: Mostly Predictive, Low Predictive, Baseline) x Order (6 levels) x Age-Group (3 levels) mixed ANOVAs were conducted on average cueing ratios on singleton-absent trials for response times and accuracy.

Response Time

The Block x Order x Age-Group interaction was non-significant ($F(17.60, 195.40) = 1.58$, $p = .069$, $\eta_p^2 = .13$; *see Table 3.3.1*). The Block x Order interaction ($F(8.80, 195.40) = 1.19$, $p = .304$, $\eta_p^2 = .05$) and the Order x Age-Group interaction ($F(10, 111) = .80$, $p = .625$, $\eta_p^2 = .07$) were both not significant. The main effect of Order was not significant ($F(5, 111) = 2.04$, $p = .079$, $\eta_p^2 = .08$). The Block x Age-Group interaction and main effects of Block and Age-Group were all significant and replicated the findings reported in

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[37] There were six possible orders for the three block conditions. The order of the three block conditions was counterbalanced for nine- to 11-year-olds and adults. But the counterbalancing of order was not achieved for the five- to six-year-old age-group due to experimenter error with four participants. For this group, three orders (out of six) were repeated but no order was repeated more than one, or in one case, two additional times.

Chapter 3. Based on the findings above, the order of the block conditions did not influence cue-utilisation in all age-groups.

Accuracy

The findings replicate the those reported above, as the Block x Order x Age-Group interaction was non-significant ($F(15.33, 170.19) = .79$, $p = .685$, $\eta_p^2 = .07$; *see Table 3.3.2*). All other interactions with Order (Block x Order: $F(7.67, 170.19) = .77$, $p = .625$, $\eta_p^2 = .03$; Order x Age-Group: $F(10, 111) = .68$, $p = .74$, $\eta_p^2 = .06$) and the main effect of Order were not significant ($F(5, 111) = 1.20$, $p = .315$, $\eta_p^2 = .05$). The main effect of Block was significant and is reported in Chapter 3.

Overall, the findings from both response times and accuracy show that the order which participants completed the block conditions, did not influence cue-utilisation performance on singleton-absent trials across all age-groups.

Attentional Capture

If block order influenced attentional capture, it is expected that participants would have greater experience with the singleton distracter and so would experience more attentional capture in the first block they completed relative to the last block. Separate Block x Cue Validity (valid, invalid) x Order x Age-Group mixed ANOVAs were conducted on average distraction ratios for response times and accuracy. Cue Validity was added to this analysis to understand if order effects influenced our main predictions concerning the reduction of attentional capture on valid trials in the Mostly Predictive block, reported in Chapter 3.

Table 3.3.1. Average cueing ratios for response times (standard error [95% confidence intervals]) for six block orders in three age-groups.

		M – L – B	*M – B – L*	*L – B – M*	*L – M – B*	*B – M – L*	*B – L – M*
5- to 6-year-olds	*Mostly Predictive*	1.08 (.07 [.94, 1.21])	.98 (.06 [.86, 1.11])	1.04 (.07 [.91, 1.18])	1.12 (.06 [.99, 1.25])	1.11 (.07 [.97, 1.26])	1.05 (.06 [.93, 1.17])
	Low Predictive	1.11 (.05 [1.01, 1.20])	1.06 (.05 [.97, 1.15])	1.05 (.05 [.95, 1.15])	.97 (.05 [.87, 1.06])	.97 (.05 [.86, 1.07])	.99 (.04 [.90, 1.08])
	Baseline	.95 (.04 [.87, 1.04])	1.09 (.04 [1.01, 1.17])	.96 (.04 [.88, 1.05])	1.02 (.04 [.94, 1.10])	1.03 (.05 [.94, 1.13])	.95 (.04 [.87, 1.02])
9- to 11-year-olds	*Mostly Predictive*	1.26 (.07 [1.12, 1.39])	1.41 (.07 [1.28, 1.55])	1.11 (.07 [.98, 1.25])	1.15 (.07 [1.01, 1.28])	1.13 (.07 [1.00, 1.27])	1.14 (.07 [1.00, 1.27])
	Low Predictive	1.13 (.05 [1.03, 1.23])	1.13 (.05 [1.03, 1.23])	1.12 (.05 [1.02, 1.21])	1.06 (.05 [.96, 1.15])	1.04 (.05 [.94, 1.14])	1.01 (.05 [.92, 1.11])
	Baseline	.95 (.04 [.87, 1.04])	1.01 (.04 [.92, 1.09])	1.01 (.04 [.92, 1.10])	1.04 (.04 [.95, 1.12])	.99 (.04 [.91, 1.08])	1.00 (.04 [.91, 1.08])
Adults	*Mostly Predictive*	1.30 (.07 [1.16, 1.43])	1.31 (.07 [1.17, 1.44])	1.18 (.07 [1.05, 1.32])	1.39 (.07 [1.25, 1.52])	1.22 (.07 [1.09, 1.36])	1.33 (.07 [1.20, 1.47])
	Low Predictive	1.15 (.05 [1.05, 1.25])	1.20 (.05 [1.11, 1.30])	1.06 (.05 [.96, 1.16])	1.21 (.05 [1.11, 1.31])	1.06 (.05 [.96, 1.16])	1.12 (.05 [1.02, 1.21])
	Baseline	.97 (.04 [.89, 1.06])	.97 (.04 [.89, 1.06])	.99 (.04 [.90, 1.07])	.97 (.04 [.88, 1.06])	.99 (.04 [.90, 1.07])	.98 (.04 [.89, 1.07])

Note: Order of block completion is denoted by: M – Mostly Predictive; L – Low Predictive; B – Baseline.

Table 3.3.2. Average cueing ratios for accuracy (standard error [95% confidence intervals]) for six block orders in three age-groups.

		M – L – B	*M – B – L*	*L – B – M*	*L – M – B*	*B – M – L*	*B – L – M*
5- to 6-year-olds	*Mostly Predictive*	1.00 (.04 [.91, 1.08])	1.03 (.04 [.95, 1.11])	1.02 (.04 [.94, 1.10])	1.04 (.04 [.96, 1.12])	1.01 (.05 [.92, 1.10])	1.02 (.04 [.94, 1.09])
	Low Predictive	1.01 (.02 [.97, 1.05])	1.01 (.02 [.97, 1.04])	1.01 (.02 [.97, 1.04])	1.02 (.02 [.99, 1.06])	1.01 (.02 [.97, 1.05])	.98 (.02 [.95, 1.01])
	Baseline	1.00 (.02 [.96, 1.04])	1.02 (.02 [.99, 1.06])	1.00 (.02 [.95, 1.04])	.99 (.02 [.95, 1.03])	1.00 (.02 [.96, 1.05])	.97 (.02 [.93, 1.01])
9- to 11-year-olds	*Mostly Predictive*	1.08 (.04 [1.00, 1.16])	1.17 (.04 [1.09, 1.25])	1.05 (.04 [.96, 1.13])	1.04 (.04 [.95, 1.12])	.99 (.04 [.91, 1.07])	1.00 (.04 [.91, 1.08])
	Low Predictive	1.01 (.02 [.97, 1.04])	.99 (.02 [.95, 1.03])	1.00 (.02 [.96, 1.04])	.99 (.02 [.96, 1.03])	1.00 (.02 [.96, 1.04])	1.01 (.02 [.98, 1.05])
	Baseline	.97 (.02 [.93, 1.01])	.97 (.02 [.93, 1.01])	1.01 (.02 [.97, 1.05])	.98 (.02 [.94, 1.02])	.99 (.02 [.95, 1.03])	.98 (.02 [.94, 1.02])
Adults	*Mostly Predictive*	1.06 (.04 [.97, 1.14])	1.03 (.04 [.94, 1.11])	1.03 (.04 [.95, 1.11])	1.03 (.04 [.95, 1.11])	1.02 (.04 [.94, 1.11])	1.01 (.04 [.93, 1.10])
	Low Predictive	1.03 (.02 [.99, 1.06])	1.00 (.02 [.97, 1.04])	1.00 (.02 [.96, 1.04])	1.00 (.02 [.96, 1.03])	1.02 (.02 [.98, 1.06])	1.02 (.02 [.98, 1.05])
	Baseline	.99 (.02 [.94, 1.03])	1.01 (.02 [.97, 1.05])	.99 (.02 [.95, 1.03])	.98 (.02 [.94, 1.02])	1.02 (.02 [.97, 1.06])	1.00 (.02 [.96, 1.04])

Note: Order of block completion is denoted by: M – Mostly Predictive; L – Low Predictive; B – Baseline.

Response Time

The Block x Cue Validity x Order x Age-Group interaction was not significant (*F*(20, 222) = 1.42, *p* = .117, η_p^2 = .11; *see Tables 3.3.3A & 3.3.3B*). The Block x Order interaction was significant (*F*(20, 222) = 1.42, *p* = .117, η_p^2 = .11). This showed that participants who completed the Baseline – Low Predictive – Mostly Predictive block order, had larger distraction ratios in the Baseline block compared to the Mostly Predictive (*p* = .024) and Low Predictive blocks (*p* = .013). No difference was found between Mostly Predictive and Low Predictive blocks in this order (*p* = 1.00). Participants who completed the Low Predictive – Baseline – Mostly Predictive block order, had larger distraction ratios in the Low Predictive block relative to the Mostly Predictive block (*p* = .042). No differences were found between other block conditions in this order (all *ps* > .08). No further differences were found between blocks for all other Orders (all *ps* > .05). Comparisons between Orders showed that participants who completed the Low Predictive – Baseline – Mostly Predictive block order, had larger distraction ratios in the Low Predictive block only, relative to those who completed the Baseline – Low Predictive – Mostly Predictive block order (*p* = .014). No further differences were found between Orders across block conditions (all *ps* > .05). All other main effects and interactions were non-significant (except the main effect of Age-Group) and replicated the reported findings in Chapter 3. All other non-significant findings with Order are reported in Table 3.3.4.

This analysis shows that participants in two of the six orders experienced, as predicted, more distraction on the first block relative to the last block condition they completed. This pattern of findings was expected to occur but it is important to note that these results were 1) not found for all orders, 2) were not specific to one age-group or one type of block (as order influenced both Baseline and Low Predictive blocks in two cases they were presented first) and 3) did not interact with other variables of interest (i.e. Cue Validity). Thus, the order effects found in this task suggest that, in some cases, participants experienced less attentional capture as they became more practiced with the task.

Table 3.3.3A. Average distraction ratios (standard error [95% confidence intervals]) for response time on **valid trials** for six block orders in three age-groups.

		M – L – B	*M – B – L*	*L – B – M*	*L – M – B*	*B – M – L*	*B – L – M*
5- to 6-year-olds	*Mostly Predictive*	1.08 (.04 [1.01, 1.14])	1.08 (.03 [1.01, 1.14])	1.17 (.04 [1.10, 1.23])	1.03 (.03 [.97, 1.10])	1.00 (.04 [.93, 1.07])	1.09 (.03 [1.03, 1.15])
	Low Predictive	1.18 (.05 [1.09, 1.27])	1.11 (.04 [1.03, 1.20])	1.24 (.05 [1.15, 1.33])	1.03 (.04 [.94, 1.11])	1.01 (.05 [.92, 1.11])	1.04 (.04 [.96, 1.12])
	Baseline	.92 (.04 [.84, 1.00])	1.04 (.04 [.97, 1.11])	.99 (.04 [.91, 1.07])	1.09 (.04 [1.02, 1.17])	1.09 (.04 [1.01, 1.18])	1.10 (.04 [1.03, 1.17])
9- to 11-year-olds	*Mostly Predictive*	1.10 (.04 [1.03, 1.17])	1.12 (.04 [1.05, 1.19])	1.02 (.04 [.95, 1.09])	1.04 (.04 [.98, 1.11])	1.08 (.04 [1.01, 1.15])	1.03 (.04 [.96, 1.10])
	Low Predictive	1.07 (.05 [.98, 1.16])	1.07 (.05 [.98, 1.16])	1.12 (.05 [1.03, 1.22])	1.06 (.05 [.97, 1.15])	1.03 (.05 [.94, 1.13])	1.03 (.05 [.94, 1.12])
	Baseline	1.09 (.04 [1.01, 1.16])	1.07 (.04 [.99, 1.14])	1.12 (.04 [1.04, 1.20])	1.07 (.04 [.99, 1.15])	1.09 (.04 [1.01, 1.17])	1.12 (.04 [1.04, 1.19])
Adults	*Mostly Predictive*	1.08 (.04 [1.01, 1.15])	1.03 (.04 [.97, 1.10])	1.04 (.04 [.97, 1.11])	1.02 (.04 [.95, 1.09])	1.05 (.04 [.98, 1.12])	1.00 (.04 [.93, 1.07])
	Low Predictive	1.06 (.05 [.97, 1.15])	1.06 (.05 [.97, 1.15])	1.05 (.05 [.96, 1.14])	1.10 (.05 [1.01, 1.20])	1.05 (.05 [.95, 1.14])	1.02 (.05 [.93, 1.11])
	Baseline	1.01 (.04 [.93, 1.08])	1.02 (.04 [.94, 1.10])	1.05 (.04 [.97, 1.13])	1.05 (.04 [.97, 1.13])	1.04 (.04 [.96, 1.12])	1.01 (.04 [.98, 1.13])

Note: M – Mostly Predictive block; L – Low Predictive block; B – Baseline block.

Table 3.3.3B. Average distraction ratios (standard error [95% confidence intervals]) for response time on **invalid trials** for six block orders in three age-groups.

		M – L – B	*M – B – L*	*L – B – M*	*L – M – B*	*B – M – L*	*B – L – M*
5- to 6-year-olds	*Mostly Predictive*	1.05 (.05 [.95, 1.16])	1.18 (.05 [1.09, 1.28])	1.07 (.05 [.97, 1.17])	1.03 (.05 [.93, 1.12])	1.00 (.06 [.88, 1.11])	1.03 (.05 [.93, 1.12])
	Low Predictive	1.07 (.04 [1.00, 1.14])	1.05 (.03 [.98, 1.11])	1.21 (.04 [1.14, 1.28])	1.11 (.03 [1.04, 1.17])	1.12 (.04 [1.04, 1.19])	1.11 (.03 [1.06, 1.17])
	Baseline	1.06 (.05 [.97, 1.16])	1.00 (.04 [.92, 1.09])	1.11 (.05 [1.02, 1.21])	1.09 (.04 [1.01, 1.18])	.99 (.05 [.89, 1.09])	1.22 (.04 [1.14, 1.30])
9- to 11-year-olds	*Mostly Predictive*	1.10 (.05 [1.00, 1.21])	1.04 (.05 [.94, 1.14])	1.11 (.05 [1.00, 1.21])	1.08 (.05 [.98, 1.18])	1.09 (.05 [.98, 1.19])	1.10 (.05 [1.00, 1.21])
	Low Predictive	1.04 (.04 [.97, 1.11])	1.06 (.04 [.99, 1.13])	1.10 (.04 [1.03, 1.17])	1.17 (.04 [1.10, 1.24])	1.08 (.04 [1.01, 1.15])	1.08 (.04 [1.01, 1.15])
	Baseline	1.14 (.05 [1.04, 1.23])	1.08 (.05 [.98, 1.17])	1.12 (.05 [1.03, 1.22])	1.03 (.05 [.94, 1.13])	1.11 (.05 [1.02, 1.20])	1.13 (.05 [1.04, 1.22])
Adults	*Mostly Predictive*	1.04 (.05 [.94, 1.14])	1.08 (.05 [.98, 1.18])	1.03 (.05 [.92, 1.13])	1.03 (.05 [.93, 1.14])	1.06 (.05 [.96, 1.16])	1.02 (.05 [.92, 1.13])
	Low Predictive	1.03 (.04 [.96, 1.10])	1.06 (.04 [.99, 1.13])	1.07 (.04 [1.00, 1.13])	1.07 (.04 [1.00, 1.13])	1.07 (.04 [1.00, 1.14])	1.03 (.04 [.96, 1.10])
	Baseline	1.03 (.05 [.94, 1.13])	1.08 (.05 [.99, 1.17])	1.09 (.05 [1.00, 1.19])	1.09 (.05 [.99, 1.18])	1.08 (.05 [.99, 1.17])	1.06 (.05 [.97, 1.15])

Note: M – Mostly Predictive block; L – Low Predictive block; B – Baseline block.

Table 3.3.4. F-statistics for the remaining main effect and interactions which did not meet significance in the Block x Cue Validity x Age-Group x Order mixed ANOVA on average distraction ratios for response times.

	$F(\text{df}_1, \text{df}_2)$ = statistic	p	η_p^2
Order	$F(5, 111) = 1.14$	.342	.05
Cue Validity x Order	$F(5, 111) = .48$	.789	.02
Age-Group x Order	$F(10, 111) = .99$	.458	.08
Cue Validity x Age-Group x Order	$F(10, 111) = .35$	.964	.03
Block x Cue Validity x Order	$F(10, 222) = 1.36$	.203	.06

Accuracy

The Block x Cue Validity x Order x Age-Group interaction was not significant ($F(20, 222) = .86$, $p = .635$, $\eta_p^2 = .07$; *see Tables 3.3.5A & 3.3.5B overleaf*). The main effect and interactions with Order were also not significant (*see Table 3.3.6*). All other interactions and main effects were non-significant and are reported in Chapter 3.

Overall, order effects influenced participants' experience of attentional capture for response times only. This type of order effect in the Cued Visual Search task should not be taken as a cause for concern as they did not influence cue-utilisation but they did reduce attentional capture effects in some cases. This could be due to participants gaining more experience with the singleton distracter, which is known to influence attentional capture (Gaspelin et al., 2021).

Table 3.3.6. F-statistics for the remaining main effect and interactions which did not meet significance in the Block x Cue Validity x Age-Group x Order mixed ANOVA on average distraction ratios for accuracy.

	$F(\text{df}_1, \text{df}_2)$ = statistic	p	η_p^2
Order	$F(5, 111) = .76$	.581	.03
Cue Validity x Order	$F(5, 111) = .53$	.756	.02
Age-Group x Order	$F(10, 111) = 1.27$	.255	.10
Cue Validity x Age-Group x Order	$F(10, 111) = .27$	.986	.02
Block x Cue Validity x Order	$F(10, 222) = .26$	.989	.01

Table 3.3.5A. Average distraction ratios (standard error [95% confidence intervals]) for accuracy on **valid trials** for six block orders in three age-groups.

		M – L – B	*M – B – L*	*L – B – M*	*L – M – B*	*B – M – L*	*B – L – M*
5- to 6-year-olds	*Mostly Predictive*	1.00 (.02 [.96, 1.03])	1.01 (.02 [.98, 1.04])	1.02 (.02 [.99, 1.05])	1.01 (.02 [.99, 1.04])	.99 (.02 [.96, 1.03])	1.00 (.01 [.97, 1.03])
	Low Predictive	1.01 (.03 [.96, 1.06])	1.03 (.02 [.98, 1.08])	1.01 (.03 [.96, 1.06])	1.01 (.02 [.97, 1.06])	1.02 (.03 [.97, 1.07])	1.00 (.02 [.96, 1.04])
	Baseline	1.01 (.02 [.98, 1.04])	1.01 (.01 [.98, 1.03])	1.00 (.02 [.97, 1.03])	1.01 (.01 [.98, 1.03])	1.01 (.02 [.98, 1.04])	.97 (.01 [.95, 1.00])
9- to 11-year-olds	*Mostly Predictive*	1.01 (.02 [.98, 1.04])	.99 (.02 [.95, 1.02])	.99 (.02 [.96, 1.02])	1.05 (.02 [1.01, 1.08])	1.03 (.02 [1.00, 1.06])	.98 (.02 [.94, 1.01])
	Low Predictive	.99 (.03 [.94, 1.04])	.98 (.03 [.93, 1.03])	1.01 (.03 [.96, 1.06])	1.01 (.03 [.96, 1.06])	.99 (.03 [.94, 1.04])	1.01 (.03 [.96, 1.06])
	Baseline	1.00 (.02 [.98, 1.03])	.98 (.02 [.95, 1.01])	1.00 (.02 [.97, 1.03])	.98 (.02 [.95, 1.01])	.99 (.02 [.96, 1.02])	1.01 (.02 [.98, 1.04])
Adults	*Mostly Predictive*	1.01 (.02 [.98, 1.04])	1.02 (.02 [.98, 1.05])	1.02 (.02 [.98, 1.05])	1.00 (.02 [.97, 1.04])	1.00 (.02 [.97, 1.03])	1.00 (.02 [.96, 1.03])
	Low Predictive	.99 (.03 [.95, 1.04])	1.01 (.03 [.96, 1.05])	1.02 (.03 [.97, 1.06])	1.03 (.03 [.98, 1.08])	1.01 (.03 [.96, 1.06])	1.00 (.03 [.95, 1.05])
	Baseline	.99 (.02 [.96, 1.02])	1.01 (.02 [.98, 1.04])	1.01 (.02 [.98, 1.04])	1.00 (.02 [.97, 1.03])	1.00 (.02 [.97, 1.03])	.99 (.02 [.96, 1.02])

Note: M – Mostly Predictive block; L – Low Predictive block; B – Baseline block.

Table 3.3.5B. Average distraction ratios (standard error [95% confidence intervals]) for accuracy on **invalid trials** for six block orders in three age-groups.

		M – L – B	*M – B – L*	*L – B – M*	*L – M – B*	*B – M – L*	*B – L – M*
5- to 6-year-olds	*Mostly Predictive*	1.03 (.03 [.97, 1.08])	1.03 (.03 [.98, 1.09])	.99 (.03 [.93, 1.04])	.99 (.03 [.93, 1.04])	.97 (.03 [.91, 1.03])	1.00 (.03 [.95, 1.05])
	Low Predictive	1.00 (.02 [.97, 1.03])	1.01 (.02 [.98, 1.04])	1.00 (.02 [.97, 1.03])	1.02 (.02 [.99, 1.05])	.99 (.02 [.96, 1.03])	1.01 (.01 [.98, 1.04])
	Baseline	.98 (.02 [.94, 1.02])	.98 (.02 [.95, 1.02])	1.00 (.02 [.96, 1.04])	.99 (.02 [.95, 1.02])	1.03 (.02 [.99, 1.08])	1.00 (.02 [.96, 1.04])
9- to 11-year-olds	*Mostly Predictive*	.99 (.03 [.94, 1.05])	.92 (.03 [.86, .97])	.99 (.03 [.93, 1.04])	1.00 (.03 [.94, 1.05])	1.05 (.03 [.99, 1.10])	1.02 (.03 [.97, 1.08])
	Low Predictive	1.03 (.02 [.99, 1.06])	.99 (.02 [.96, 1.03])	1.02 (.02 [.99, 1.05])	1.00 (.02 [.97, 1.03])	1.02 (.02 [.99, 1.06])	.99 (.02 [.96, 1.02])
	Baseline	1.01 (.02 [.97, 1.05])	1.02 (.02 [.98, 1.06])	1.03 (.02 [.99, 1.08])	1.03 (.02 [.99, 1.07])	1.01 (.02 [.96, 1.05])	1.02 (.02 [.98, 1.06])
Adults	*Mostly Predictive*	.97 (.03 [.92, 1.03])	.98 (.03 [.92, 1.04])	1.00 (.03 [.94, 1.06])	1.01 (.03 [.95, 1.06])	.99 (.03 [.93, 1.05])	1.00 (.03 [.94, 1.06])
	Low Predictive	.98 (.02 [.94, 1.01])	1.00 (.02 [.96, 1.03])	1.01 (.02 [.98, 1.04])	1.01 (.02 [.97, 1.04])	1.00 (.02 [.97, 1.04])	1.00 (.02 [.97, 1.03])
	Baseline	1.02 (.02 [.98, 1.06])	1.00 (.02 [.96, 1.04])	1.02 (.02 [.98, 1.06])	1.01 (.02 [.96, 1.05])	.98 (.02 [.94, 1.02])	1.00 (.02 [.96, 1.04])

Note: M – Mostly Predictive block; L – Low Predictive block; B – Baseline block.

Appendix 3.4. The Influence of Simon Effects on Cue-Utilisation and Attentional Capture

In the Cued Visual Search task, the orientation of the target line (tilted left or right by 45°) and the location of the target line in each of the four quadrants of the screen, were both counterbalanced in each block condition. In each block, there were trials where the orientation of target line and its quadrant location on the screen corresponded with one another and other trials where they did not. For instance, when the target line was tilted to the *left* and was positioned in one of the quadrants on the *left*-hand side of the screen, there is high correspondence for making a *left*-button response. This type of trial will be referred to as a "same" trial. Alternatively, when the target line was tilted to the *left* but was positioned in one of the quadrants on the *right*-hand side of the screen, there is low correspondence for making a *left*-button response. This type of trial will be referred to as an "opposite" trial. Past research has shown that participants are slower and less accurate on opposite trials compared to same trials, because participants experienced greater conflict and inhibition at the response level on opposite trials; this is often referred to as a *Simon effect* (Ambrosi et al., 2016; Pratte, Rouder, Morey & Feng, 2010). Therefore, despite target orientation being of key relevance in the Cued Visual Search task, the irrelevance of the target's location on the screen can have an impact on performance at the response level.

To assess the presence of Simon effects in the Cued Visual Search task, exploratory analyses were conducted. This is of particular importance for understanding the "noise" in the Baseline block as 1) a difference in distraction ratios could have been driven by a difference between assigned "valid" and "invalid" trials in the Baseline block and 2) a positive correlation in cueing ratios (on singleton-absent trials) and distraction ratios within the Baseline block was found for all three age-groups. To reiterate, the counterbalancing of trials for target orientation and target location was kept constant across all three block conditions. The assignment of "valid" and "invalid" labels to trials in the Baseline block matched the Mostly Predictive block and thus, the target orientation and target location on each trial was matched between the block conditions. Therefore, if Simon effects are present in the Cued Visual Search task, it is expected to be present in all block conditions.

However, Simon effects may be reduced in block conditions which include a cue that directly guides attention to an item in the search-display (Mostly Predictive & Low Predictive blocks) compared to the Baseline block which consists of cues that do not directly guide attention (i.e. cued colour is absent from the search-display). Some have shown non-significant differences in Simon effects between endogenous and exogenous control processes (Proctor, Zu & Van Zandt, 1992; Verfaellie, Bowers & Heilman, 1988). Others have shown that early cues which guide attention towards the target location lead to reduced Simon effects, relative to a Baseline block which consists of only neutral cues (Abrahamse & Van der Lubbe, 2008; Umiltá & Liotti, 1987). The inclusion of an early cue can create a perceptual feature map for the target, which may modulate the influence of stimulus-response mappings (Abrahamse & Van der Lubbe, 2008). In contrast, a neutral cue has little influence of guiding attention and so the influence of stimulus-response mappings may be more pronounced in the Baseline block. To further investigate this, exploratory analyses were conducted to understand if Simon effects influence cue-utilisation and attentional capture effects.

Trials were coded as “same” and “opposite” based on the correspondence between the orientation of the target (L/R) and the side of the screen the target was located on (L/R quadrants; *see Table 3.4.1*). Target location was defined by the vertical axis as participants made left and right button responses using the ‘z’ and ‘/’ keys which was also based on the vertical axis of the screen.

If Simon effects differ between block conditions, I would expect larger Simon effects in the Baseline block compared to the Mostly Predictive and Low Predictive blocks which consist of cues that direct attention (Abrahamse & Van der Lubbe, 2008; Umiltá & Liotti, 1987). Separate Block (3levels: Mostly Predictive, Low Predictive, Baseline) x Simon (2 levels: same, opposite) x Age-

Group mixed ANOVAs were conducted on cueing ratios (singleton-absent trials) for response times and accuracy data. See Tables 3.4.2 and 3.4.3 for the untransformed datasets.

Table 3.4.1. The coding of same and opposite trials based on target orientation and target location.

Target Orientation	*Target Location*	*Code*
45° left	Q1, Q3 (left)	Same
45° right	Q2, Q4 (right)	Same
45° left	Q2, Q4 (right)	Opposite
45° right	Q1, Q3 (left)	Opposite

Note: Q – Quadrant. Left screen side: Q1 and Q3 represent the top- and bottom-left on vertical axis; Right screen side: Q2 and Q4 represent top- and bottom-right on vertical axis.

Cue-Utilisation

Response Time

The Block x Simon x Age-Group interaction was not significant (*F*(3.55, 223.53) = .34, *p* = .826, η_p^2 = .01; *see Table 3.4.4*). The main effect of Simon (*F*(1, 126) = 1.43, *p* = .234, η_p^2 = .01), the Block x Simon (*F*(1.77, 223.53) = 1.40, *p* = .248, η_p^2 = .01) and the Simon x Age-Group (*F*(2, 126) = .53, *p* = .589, η_p^2 = .01) interactions were all non-significant. The remaining main effects and interactions are reported in Chapter 3.

Accuracy

The Block x Simon x Age-Group interaction was also not significant (*F*(4, 252) = 1.20, *p* = .312, η_p^2 = .02; *see Table 3.4.5*). The main effect of Simon (*F*(1, 126) = 1.66, *p* = .201, η_p^2 = .01) and both interaction terms with Simon (Block x Simon: *F*(2, 252) = .62, *p* = .537, η_p^2 = .01; Simon x Age-Group: *F*(2, 126) = .63, *p* = .533, η_p^2 = .01) were not significant. The remaining main effects and interactions are reported in Chapter 3.

Table 3.4.2. Untransformed average median response times, standard error and 95% confidence intervals across all variables including same and opposite trials. Singleton-absent and singleton-present trials are presented in the top and bottom panels respectively.

				5- to 6-year-olds			*9- 11-year-olds*			*Adults*		
				M	*SE*	*95% CI*	*M*	*SE*	*95% CI*	*M*	*SE*	*95% CI*
Singleton-Absent Trials	*Mostly Predictive*	*Valid*	*Same*	1.51	.07	1.37, 1.64	.83	.03	.78, .89	.67	.01	.54, .59
			Opposite	1.62	.08	1.46, 1.79	.92	.05	.82, 1.01	.59	.01	.57, .62
		Invalid	*Same*	1.60	.09	1.42, 1.78	1.00	.05	.90, 1.09	.71	.03	.66, .77
			Opposite	1.70	.09	1.51, 1.89	1.05	.05	.94, 1.16	.75	.03	.70, .80
	Low Predictive	*Valid*	*Same*	1.53	.07	1.39, 1.68	.92	.05	.82, 1.01	.59	.01	.56, .61
			Opposite	1.69	.10	1.48, 1.89	.94	.05	.84, 1.03	.61	.01	.58, .63
		Invalid	*Same*	1.48	.06	1.36, 1.60	.95	.04	.87, 1.02	.66	.02	.62, .69
			Opposite	1.66	.07	1.52, 1.81	1.02	.05	.92, 1.12	.69	.02	.65, .73
	Baseline	*Valid*	*Same*	1.52	.07	1.38, 1.67	.87	.04	.80, .95	.60	.02	.57, .63
			Opposite	1.71	.09	1.53, 1.88	.98	.05	.88, 1.08	.64	.02	.61, .68
		Invalid	*Same*	1.59	.10	1.40, 1.79	.89	.04	.82, .97	.60	.02	.57, .63
			Opposite	1.93	.19	1.54, 2.31	1.03	.07	.88, 1.17	.66	.02	.62, .70
Singleton-Present Trials	*Mostly Predictive*	*Valid*	*Same*	1.54	.06	1.41, 1.68	.87	.03	.80, .93	.58	.02	.55, .61
			Opposite	1.78	.10	1.58, 1.99	.98	.04	.89, 1.06	.62	.02	.59, .65
		Invalid	*Same*	1.65	.07	1.51, 1.80	1.07	.05	.96, 1.18	.74	.03	.69, .80
			Opposite	1.82	.09	1.63, 2.01	1.18	.05	1.07, 1.29	.81	.03	.75, .88
	Low Predictive	*Valid*	*Same*	1.68	.08	1.51, 1.84	.92	.05	.83, 1.02	.60	.01	.58, .62
			Opposite	1.75	.08	1.58, 1.91	1.04	.06	.92, 1.17	.65	.01	.62, .67
		Invalid	*Same*	1.69	.08	1.53, 1.84	1.04	.05	.93, 1.15	.68	.02	.64, .73
			Opposite	1.77	.07	1.62, 1.92	1.10	.05	1.00, 1.21	.75	.02	.70, .79
	Baseline	*Valid*	*Same*	1.67	.11	1.45, 1.88	.96	.04	.87, 1.05	.61	.02	.58, .64
			Opposite	1.73	.08	1.58, 1.89	1.07	.05	.97, 1.17	.68	.02	.64, .71
		Invalid	*Same*	1.70	.09	1.51, 1.89	.96	.05	.87, 1.06	.63	.02	.60, .66
			Opposite	1.86	.09	1.67, 2.04	1.07	.05	.97, 1.17	.69	.02	.65, .73

Table 3.4.3. Untransformed average accuracy, standard error and 95% confidence intervals across all variables including same and opposite trials. Singleton-absent and singleton-present trials are presented in the top and bottom panels respectively.

				5- to 6-year-olds			*9- 11-year-olds*			*Adults*		
				M	*SE*	*95% CI*	*M*	*SE*	*95% CI*	*M*	*SE*	*95% CI*
Singleton-Absent Trials	*Mostly Predictive*	*Valid*	*Same*	.97	.01	.96, .99	.98	.01	.97, .99	.99	.002	.98, .99
			Opposite	.95	.01	.92, .97	.94	.01	.92, .97	.96	.01	.95, .97
		Invalid	*Same*	.96	.01	.94, .98	.96	.02	.93, 1.00	.97	.01	.95, .99
			Opposite	.94	.01	.92, .97	.91	.02	.88, .95	.94	.01	.92, .96
	Low Predictive	*Valid*	*Same*	.98	.01	.97, 1.00	.98	.01	.97, 1.00	.99	.004	.98, 1.00
			Opposite	.95	.01	.92, .98	.94	.02	.91, .97	.96	.01	.94, .98
		Invalid	*Same*	.98	.01	.97, .99	.98	.004	.97, .99	.98	.004	.97, .99
			Opposite	.96	.01	.94, .97	.95	.01	.93, .97	.95	.01	.94, .96
	Baseline	*Valid*	*Same*	.98	.01	.97, .99	.98	.01	.97, .99	.98	.004	.98, .99
			Opposite	.94	.01	.93, .96	.94	.01	.92, .96	.96	.01	.94, .97
		Invalid	*Same*	.97	.01	.96, .99	.98	.01	.97, 1.00	.98	.01	.97, .99
			Opposite	.92	.02	.87, .96	.97	.02	.94, 1.00	.95	.01	.93, .98
Singleton-Present Trials	*Mostly Predictive*	*Valid*	*Same*	.98	.01	.97, 1.00	.99	.004	.99, 1.00	.99	.01	.97, 1.00
			Opposite	.94	.01	.91, .96	.93	.01	.90, .96	.96	.01	.94, .97
		Invalid	*Same*	.97	.01	.95, .99	.96	.01	.94, .98	.98	.005	.97, .99
			Opposite	.93	.02	.89, .96	.91	.02	.87, .94	.94	.01	.92, .96
	Low Predictive	*Valid*	*Same*	.98	.01	.97, 1.00	.99	.005	.98, 1.00	.98	.005	.97, .99
			Opposite	.94	.01	.92, .97	.95	.01	.93, .97	.96	.01	.94, .97
		Invalid	*Same*	.99	.01	.98, 1.00	.98	.01	.97, .99	.98	.004	.98, .99
			Opposite	.94	.01	.91, .96	.93	.01	.90, .96	.95	.01	.93, .97
	Baseline	*Valid*	*Same*	.99	.01	.97, 1.00	.99	.005	.98, 1.00	.99	.003	.99, 1.00
			Opposite	.94	.01	.91, .96	.94	.01	.92, .96	.95	.01	.93, .97
		Invalid	*Same*	.99	.01	.98, 1.00	.98	.01	.97, 1.00	.99	.004	.98, 1.00
			Opposite	.95	.01	.92, .98	.93	.01	.91, .96	.95	.01	.93, .97

Table 3.4.4. Average cueing ratios for response time, standard error and 95% confidence intervals across block and same and opposite trials for three age-groups.

		5- to 6-year-olds			*9- to 11-year-olds*			*Adults*		
		M	*SE*	*95% CI*	*M*	*SE*	*95% CI*	*M*	*SE*	*95% CI*
Mostly Predictive	*Same*	1.07	.04	.99, 1.14	1.20	.04	1.13, 1.28	1.27	.04	1.19, 1.35
	Opposite	1.06	.03	1.00, 1.12	1.16	.03	1.10, 1.23	1.27	.03	1.21, 1.33
Low Predictive	*Same*	1.00	.02	.95, 1.05	1.07	.03	1.02, 1.12	1.12	.03	1.07, 1.17
	Opposite	1.03	.02	.95, 1.05	1.10	.03	1.05, 1.15	1.14	.03	1.10, 1.19
Baseline	*Same*	1.05	.02	1.01, 1.08	1.03	.02	.99, 1.07	1.00	.02	.97, 1.04
	Opposite	1.12	.05	1.02, 1.23	1.03	.05	.92, 1.13	1.03	.05	.92, 1.14

Table 3.4.5. Average cueing ratios for accuracy, standard error and 95% confidence intervals across block and same and opposite trials for three age-groups.

		5- to 6-year-olds			*9- to 11-year-olds*			*Adults*		
		M	*SE*	*95% CI*	*M*	*SE*	*95% CI*	*M*	*SE*	*95% CI*
Mostly Predictive	*Same*	.99	.01	.96, 1.01	.98	.01	.95, 1.01	.98	.01	.95, 1.01
	Opposite	1.00	.01	.97, 1.03	.97	.01	.94, 1.00	.98	.01	.95, 1.01
Low Predictive	*Same*	1.00	.01	.98, 1.01	1.00	.01	.99, 1.06	.99	.01	.98, 1.01
	Opposite	1.02	.02	.99, 1.05	1.02	.02	.99, 1.06	1.00	.02	.96, 1.03
Baseline	*Same*	1.00	.01	.98, 1.01	1.00	.01	.99, 1.02	1.00	.01	.98, 1.01
	Opposite	.98	.02	.94, 1.02	1.04	.02	1.00, 1.08	1.00	.02	.96, 1.04

Note: M – mean; SE – standard error; 95% CI – 95% confidence intervals [lower, upper bound].

Attentional Capture

Previous research has shown that Simon effects can be modulated by endogenous control which in turn can lead to reduced attentional capture, relative to Baseline conditions (Martín-Arévalo, Lupiáñez, Botta & Chica, 2015). If endogenous control modulates Simon effects, it is expected that attentional capture effects would be reduced in the Mostly Predictive block relative to the Baseline block. The Baseline block may have larger attentional capture effects due to the additive role of Simon effects on performance. To explore this, separate Block x Cue Validity x Simon x Age-Group mixed ANOVAs were conducted on distraction ratios for response time and accuracy data.

Response Time

The main effect and interactions with Simon were all not significant (*see Table 3.4.6*). The Block x Cue Validity x Simon x Age-Group interaction was also not significant ($F(4, 252) = .631$, $p = .641$, $\eta_p^2 = .01$; *see Table 3.4.7*). The remaining main effects and interactions are reported in Chapter 3.

Table 3.4.6. F-statistics for the remaining main effect and interactions which did not meet significance in the Block x Cue Validity x Simon x Age-Group mixed ANOVA on distraction ratios for response times.

	$F(df_1, df_2)$ = statistic	p	η_p^2
Simon	$F(1, 126) = 2.65$	.106	.02
Cue Validity x Simon	$F(1, 126) = .18$	.670	.001
Age-Group x Simon	$F(2, 126) = 2.40$	.095	.04
Cue Validity x Age-Group x Simon	$F(2, 126) = .05$	.949	.001
Block x Cue Validity x Simon	$F(4, 252) = .63$	.641	.01

Accuracy

The findings replicated the aforementioned results, as the Block x Cue Validity x Simon x Age-Group interaction was not significant ($F(4, 252) = 1.15$, $p = .336$, $\eta_p^2 = .02$; *see Table 3.4.8*). The main effect of Simon and all

Table 3.4.7. Average distraction ratios for response time, standard error and 95% confidence intervals across block and same and opposite trials for three age-groups.

			5- to 6-year-olds			*9- 11-year-olds*			*Adults*		
			M	*SE*	*95% CI*	*M*	*SE*	*95% CI*	*M*	*SE*	*95% CI*
Mostly Predictive	*Valid*	*Same*	1.04	.02	1.00, 1.08	1.05	.02	1.01, 1.09	1.02	.02	.98, 1.06
		Opposite	1.10	.02	1.06, 1.14	1.08	.02	1.04, 1.12	1.04	.02	1.00, 1.08
	Invalid	*Same*	1.07	.03	1.01, 1.13	1.10	.03	1.04, 1.17	1.05	.03	.98, 1.11
		Opposite	1.10	.03	1.05, 1.16	1.14	.03	1.08, 1.20	1.08	.03	1.02, 1.14
Low Predictive	*Valid*	*Same*	1.12	.03	1.06, 1.19	1.03	.03	.96, 1.09	1.02	.03	.96, 1.09
		Opposite	1.08	.03	1.03, 1.13	1.11	.03	1.06, 1.17	1.07	.03	1.02, 1.13
	Invalid	*Same*	1.14	.02	1.10, 1.19	1.08	.02	1.04, 1.13	1.04	.02	1.00, 1.09
		Opposite	1.08	.02	1.04, 1.12	1.10	.02	1.06, 1.14	1.08	.02	1.04, 1.12
Baseline	*Valid*	*Same*	1.10	.03	1.04, 1.16	1.10	.03	1.04, 1.17	1.02	.03	.95, 1.08
		Opposite	1.04	.02	1.00, 1.07	1.10	.02	1.07, 1.14	1.05	.02	1.01, 1.09
	Invalid	*Same*	1.09	.02	1.04, 1.13	1.07	.02	1.03, 1.11	1.05	.02	1.01, 1.09
		Opposite	1.07	.03	1.01, 1.13	1.11	.03	1.04, 1.17	1.05	.03	.99, 1.12

Note: M – mean; SE – standard error; 95% CI – 95% confidence intervals [lower, upper bound].

Table 3.4.8. Average distraction ratios for accuracy, standard error and 95% confidence intervals across block and same and opposite trials for three age-groups.

			5- to 6-year-olds			*9- 11-year-olds*			*Adults*		
			M	*SE*	*95% CI*	*M*	*SE*	*95% CI*	*M*	*SE*	*95% CI*
Mostly Predictive	*Valid*	*Same*	1.01	.01	1.00, 1.02	1.01	.01	1.00, 1.03	1.00	.01	.99, 1.01
		Opposite	.99	.01	.97, 1.02	.99	.01	.97, 1.02	1.00	.01	.97, 1.02
	Invalid	*Same*	1.02	.02	.97, 1.06	1.02	.02	.98, 1.07	1.01	.02	.97, 1.06
		Opposite	.98	.02	.95, 1.01	1.00	.02	.97, 1.04	1.00	.02	.97, 1.03
Low Predictive	*Valid*	*Same*	1.00	.01	.98, 1.02	1.01	.01	.99, 1.03	.99	.01	.97, 1.01
		Opposite	1.01	.02	.97, 1.04	1.02	.02	.99, 1.05	1.00	.02	.97, 1.03
	Invalid	*Same*	1.01	.01	1.00, 1.02	1.00	.01	.99, 1.01	1.00	.01	.99, 1.01
		Opposite	.98	.01	.95, 1.00	.98	.01	.96, 1.00	1.00	.01	.97, 1.02
Baseline	*Valid*	*Same*	1.01	.004	1.00, 1.02	1.01	.004	1.00, 1.02	1.01	.004	1.00, 1.02
		Opposite	1.00	.01	.98, 1.02	1.00	.01	.98, 1.02	1.00	.01	.98, 1.02
	Invalid	*Same*	1.02	.01	1.00, 1.03	1.00	.01	.99, 1.02	1.01	.01	.99, 1.03
		Opposite	1.07	.03	1.02, 1.12	.97	.03	.92, 1.03	1.00	.03	.95, 1.06

Note: M – mean; SE – standard error; 95% CI – 95% confidence intervals [lower, upper bound].

interactions with Simon were non-significant (*see Table 3.4.9*). The remaining main effects and interactions are reported in Chapter 3.

Table 3.4.9. F-statistics for the remaining main effect and interactions which did not meet significance in the Block x Cue Validity x Simon x Age-Group mixed ANOVA on distraction ratios for accuracy.

	$F(df_1, df_2)$ = statistic	p	η_p^2
Simon	$F(1, 126) = 3.90$	.051	.03
Cue Validity x Simon	$F(1, 126) = .52$	.472	.004
Age-Group x Simon	$F(2, 126) = .49$	.617	.01
Cue Validity x Age-Group x Simon	$F(2, 126) = .44$	.645	.01
Block x Cue Validity x Simon	$F(4, 252) = 1.82$	.164	.01

Overall, the results show non-significant Simon effects were found and they did not influence cue-utilisation and attentional capture effects across all age-groups. Specifically, Simon effects were not more prominent in the Baseline block compared to any other block condition. This opposes previous research which suggests that an early cue which guides attention can reduce Simon effects relative to a neutral cue (Abrahamse & Van der Lubbe, 2008; Martín-Arévalo et al., 2015; Umiltá & Liotti, 1987). The current findings support evidence which has shown non-significant differences in Simon effects between cued and neutral cue conditions (Proctor et al., 1992; Verfaellie et al., 1988). Therefore, based on the present results, the differences found between assigned “valid” and “invalid” trials in the Baseline block in Chapter 3 cannot be attributed to Simon effects.

Appendix 5.1. Pre-registration for the main hypotheses and analyses in Chapter 5

This pre-registration for Chapter 5 was uploaded to the Open Science Framework: Hayre, R. K., Cragg, L., & Allen, H. A. (2020, May 12). The Influence of Block Predictability On Cue Utilisation In Early- & Mid-Childhood. Retrieved from osf.io/nvmr8.

Data collection. Have any data been collected for this study already? (optional)

Please choose. Note: 'Yes' is a discouraged answer for this preregistration form.

Yes, we already collected the data.

No, no data have been collected for this study yet.

X It's complicated. We have already collected some data but explain in Question 8 why readers may consider this a valid pre-registration nevertheless.

Hypothesis. What's the main question being asked or hypothesis being tested in this study? (optional)

This study aims to understand the development of top-down control during childhood. Top-down control is defined as the ability to utilise information at an early point in time (e.g. an instruction or a 'cue') to help guide our attention towards a relevant item in our environment. In this study, we will use the cued visual search task to investigate children's ability to utilise cues in guiding their attention towards a target item on a computer screen.

In this task, participants will be asked to search for a white tilted line target and respond to its orientation (left/right) via keyboard press. This tilted line target will be presented in one of three coloured circles in the search-display; the two remaining coloured circles will both contain an irrelevant horizontal white line. Prior to seeing the search-display, participants will see a coloured cue for a short duration. A valid cue informs them of the colour the target is located within; guiding attention towards the target (e.g. pink cue matches the pink circle which contains the target). An invalid cue presents a cue which mismatches the colour the target is located within; guiding attention away from the target (e.g. pink cue presented but the target is located within the green circle in the search-display). A neutral cue presents a colour which does not match any of the coloured circles in the search-display; it is not guiding attention towards or away from the target (e.g. pink cue presented but the pink circle is absent from the search-display, the target is displayed in the blue circle). Participants will be asked to complete three within-subject block conditions. Each block condition will be manipulated to assess whether children utilise cues for attention more when they are always helpful (100% of cues are valid, Predictive block) compared to when they are mostly helpful (66.67% of cues are valid, 33.33% of cues are invalid, Mostly Predictive block) and when they are never helpful (100% of cues are neutral, Baseline block) for finding the tilted line target. We will measure participants' response times and accuracy to understand how much they were utilising the cues to guide their attention in each block condition.

We predict that older children (9-11 years) have developed top-down control and so they are expected to utilise the cues to guide their attention. They are expected to benefit from utilising the cues to find the target when they are always helpful (Predictive block) compared to when they are mostly helpful (Mostly Predictive block) and never helpful (Baseline block). In contrast, younger children (5-6 years) are not expected to have developed top-down control at this point in childhood and so we do not predict that they will utilise the cues to guide their attention in any of the block conditions.

Dependent variable. Describe the key dependent variable(s) specifying how they will be measured. (optional)

Participants will be asked to search for a white tilted-line target in the search-display and they must respond to the orientation (left/right) via keyboard press as fast and accurately as they can. Participants' accuracy (%) and median response times (in seconds) where they made an accurate response will be analysed.

Conditions. How many and which conditions will participants be assigned to? (optional)

There is one between-subjects independent variable in this study, which is age-group (2 levels: 5-6 years, 9-11 years). Participants will be asked to complete all three within-subject block conditions (3 levels: Predictive block, Mostly Predictive block, Baseline block). The order of each block condition will be counterbalanced for each age-group.

Analyses. Specify exactly which analyses you will conduct to examine the main question/hypothesis. (optional)

We will first examine whether participants benefited from using the cues to guide their attention in the different block conditions. We will assess response times and accuracy on valid and neutral trials. This will allow us to compare performance on valid trials in the Predictive block (where cues are always helpful) to valid trials in the Mostly Predictive block (where cues are mostly helpful) as well as to neutral trials in the Baseline block (where cues are never helpful). We will conduct a 3 (Block: Predictive block, Mostly Predictive block, Baseline block) x 2 (Age-Group: 5-6 years, 9-11 years) mixed Analysis of Variance on median response times (in seconds) and accuracy (%). We will conduct simple main effects analysis using Bonferroni correction for any significant main effects and/or interactions found.

We predict that a significant Block x Age-Group interaction will be found. This is because, we expect older children (9-11 years) to have developed top-down control and so they are expected to utilise the cues to guide their attention. This is expected to be shown by faster response times and better accuracy on valid trials in the Predictive block relative to valid trials in the Mostly Predictive block and neutral trials in the Baseline block. This difference is also expected to occur between valid trials in the Mostly Predictive block and neutral trials in the Baseline block. In contrast, younger children (5-6 years) are not expected to have developed top-down control and so we do not expect their response times and accuracy to significantly differ across any of the block conditions.

Our second analysis will assess if utilising the cues to guide attention resulted in participants experiencing a "cost" to their response times and accuracy when they were presented with invalid cues compared to valid cues (in the Mostly Predictive block) and compared to neutral cues (in the Baseline block). We will conduct a 3 (Cue Validity: invalid, valid, neutral) x 2 (Age-Group: 5-6 years, 9-11 years) mixed Analysis of Variance on average median response times and accuracy.

We expect to find a significant Cue Validity x Age-Group interaction. As we predict older children (9-11 years) to utilise cues to guide their attention, we expect them to have slower responses and reduced accuracy on invalid trials compared to valid trials in the Mostly Predictive block, as well as compared to neutral trials in the Baseline block. We do not expect younger children (5-6 years) to utilise the cues and so we expect their response times and accuracy across cue types to non-significantly differ from one another.

For all analyses, Greenhouse Geisser Correction will be applied if Mauchly's test of Sphericity has been violated. Simple main effects analysis with Bonferroni Correction will be conducted for any significant main effects and/or interactions found. For the second analysis with invalid trials, if a significant main effect and/or interaction is found we will not conduct a t-test comparing valid trials (from the Mostly Predictive block) and neutral trials (from the Baseline block) as this comparison would have already been conducted in the first analysis (comparing valid and neutral trials across block conditions). For all analyses, the p-value must be less than 0.01 to be classed as significant.

Outliers and Exclusions. Describe exactly how outliers will be defined and handled, and your precise rule(s) for excluding observations.(optional)

The first trial of each block condition as well as the first trial following a break interval within each block condition will be removed from the analysis. Response times which are +/- 4 standard deviations from each participant's median response time in a block condition (containing only accurate responses), will be classed as an outlier and will be removed. To assess whether there are multivariate outliers in the dataset, Mahalanobis' Distance will be calculated for each participant across all response time and accuracy data. If a participant's Mahalanobis' distance value is less than a cumulative probability of 0.001, they will be classed as a significant multivariate outlier and will be removed from further analysis. If a participant fails to complete all of the block conditions and/or has reported to have had a formal diagnosis of a visual impairment (partial vision, colour blindness, visual floaters), Autistic Spectrum Disorder and/or Attention Deficit and Hyperactivity Disorder, their data will not be included in the analysis. If a participant has had three repeat attempts at any one of the practice phases and has continued to make three or more response errors, the researcher will stop the experiment and thank the participant for their time.

Sample Size. How many observations will be collected or what will determine sample size? No need to justify decision, but be precise about exactly how the number will be determined.(optional)

A power analysis has been conducted using the procedure by D'Amico, Neilands & Zambarano (2001) and Osborne (2006). This power analysis used data from Wainwright and Bryson's (2005) study who had a similar question and task parameters to our study. This study asked four age-groups (including 5-6-year-olds: N = 14 and 9-11-year-olds: N = 13) to complete one block condition which included 80% valid cues, 10% invalid cues and 10% neutral cues. They found a significant main effect of Cue Validity (faster response times on valid relative to neutral trials and invalid trials respectively), but this did not significantly interact with Age Group. Mean response time and average standard deviation data from valid and neutral trials from the age-groups of interest were utilised in our power analysis. We used a conservative approach by powering for a Block (2 levels: Mostly Predictive – valid trials; Baseline - neutral trials) x Age-Group (2 levels: 5-6 years, 9-11 years) interaction. To acquire a power of 0.8 using an alpha criterion of 0.01, 53 participants in each age-group are required. To ensure the order of block conditions are counterbalanced we will aim for 54 participants per age-group (power = 0.817).

Other. Anything else you would like to pre-register? (e.g., secondary analyses, variables collected for exploratory purposes, unusual analyses planned?)(optional)

Data has been collected for the older children age-group at a public engagement event. This event was scheduled beyond our control and we did not want to miss the window for data collection. Data collection for the younger children began after this event, using the same methodology and is still ongoing. Data has not been accessed or looked at by any principal investigators in any way.

Name. Give a title for this AsPredicted pre-registration. Suggestion: use the name of the project, followed by study description.(optional)

The Influence of Block Predictability On Cue Utilisation In Early- & Mid-Childhood

Appendix 6.1. Pre-registration for the intended lifespan approach: hypotheses and analyses for Chapter 6

This pre-registration for Chapter 6 was uploaded to the Open Science Framework: Hayre, R. K., Cragg, L., & Allen, H. A. (2020, May 12). The Development of Top-Down Control: A Comparison of the Cued Visual Search and AX-Continuous Performance Task Across the Lifespan. Retrieved from osf.io/s9qng.

Data collection. Have any data been collected for this study already? (optional)

Please choose. Note: 'Yes' is a discouraged answer for this preregistration form.

Yes, we already collected the data.

No, no data have been collected for this study yet.

X It's complicated. We have already collected some data but explain in Question 8 why readers may consider this a valid pre-registration nevertheless.

Hypothesis. What's the main question being asked or hypothesis being tested in this study? (optional)

The current pre-registration has made some amendments from a previous pre-registration which investigates the same questions (see link: osf.io/s9qng) . These amendments include:

- For Aim 1 and 3, we will calculate cueing ratios for singleton-absent trials only in order to assess cue-use in the absence of the singleton-distracter.
- The inclusion of three dummy variable predictors in the multiple regression analysis for the assessment of Aim 3. These dummy variables

are required to ensure the data are interpretable and to assess our aim (see Analysis for Aim 3).

- Follow-up pearson's correlation coefficient analysis to understand the direction of any significant moderator predictors (see Analysis for Aim 3).
- To simplify all our analyses, we will not z-transform our data as we will be using ratio scores (cued visual search) and proactive behavioural index scores (AX-CPT) as a form of data transformation.
- Data collection is still ongoing. We have amended our power analysis to account for the inclusion of dummy variable predictors in our main analysis (Aim 3; see Sample Size section).

This study aims to understand the development of top-down control across the lifespan. Top-down control is defined as the ability to utilise information at an early stage of processing, which enables our attention to be guided towards a relevant task or item in our environment. We will ask participants from five different age-groups (5-6, 7-8, 9-11, 18-25 & 60+ years) to complete two different tasks which assess their use of top-down control. These tasks are a) the cued visual search task and b) AX Continuous Performance Task (AX CPT).

In brief, in the cued visual search task participants will be asked to search for a tilted line target presented in one of three coloured circles in the search-display; the remaining two circles will each contain a white vertical line. Prior to seeing the search-display, they will be presented with a cue (or clue) which can be used to guide attention. A valid cue will present a colour which matches the coloured circle the target is located within (e.g. a pink cue is presented and the target line is presented in a pink circle). An invalid cue presents a colour which mismatches the coloured circle the target is located within (e.g. a pink cue is presented but the target line is not located in the pink circle present in the search-display but in the blue circle). A neutral cue presents a colour which does not match any of the coloured circles in the search-display (e.g. a pink cue is presented but a pink circle is absent from the search-display, the target line is presented in the blue circle). We will ask participants to complete two block conditions of the cued visual search task: 1) Mostly Predictive block (66.67% of cues are valid, 33.33% of cues are invalid), 2) Baseline block (100% of cues are neutral). Furthermore, in each block condition, 41.67% of the trials will present an eye-catching distracter item (singleton-distracter – a black diamond), which has been piloted in a previous study to slow response times by 51ms when it was present in the search-display as opposed to when was absent.

In the AX-CPT, participants will be asked to complete one block of trials where they will be instructed to press the green button (with their dominant hand) when they see a hen followed by a cat (to be referred to as an “AX” trial type) and to press the red button (with their non-dominant hand) for all other animal combinations (i.e. AY trial type: hen-lion; BX trial type: lion-cat; BY trial type: lion-elephant). There are a total of 12 different animals presented to participants and a total of four different trial types of different proportions in the block (AX: 60% of trials; AY: 13.3% of trials; BX: 13.3% of trials; BY: 13.3% of trials).

The main question in this study is **to understand whether cue-utilisation in the Cued Visual Search task and the AX-CPT develops similarly or differently across the lifespan.** If both of these tasks tap the same underlying mechanisms, cue-utilisation in the AX-CPT will significantly predict cueing behaviour in the cued visual search task (Mostly Predictive block). We also expect that significantly more of the variance in the cued visual search task will be explained when age-effects are taken into account (included as predictors).

Secondary, we aim **to understand the development of top-down control across the lifespan.** We predict that top-down control will gradually develop from childhood to young adulthood. We expect 5-6-year-olds to have not yet developed top-down control and so we predict that they will not utilise the cues in any of the block conditions, or the AX-CPT. We expect 7-8-, 9-11-year-olds and young adults have developed the ability to utilise the cues in the AX-CPT as well as in the Mostly Predictive block of the cued visual search task relative to the Baseline block (with cue use gradually increasing with increasing age). We make two predictions for older adults, as it has been argued that top-down control is retained in older adulthood and so we would then expect older adults to utilise the cues in the AX-CPT and use the cues in the Mostly Predictive block, significantly more than Baseline (similar to young adults). On the other hand, others argue that top-down control declines in older adulthood and so we would predict that older adults will not utilise the cues in any of the conditions.

Third, we aim **to understand whether top-down control reduces attentional capture across the lifespan.** This aim specifically refers to the cued visual search task. This aim will investigate whether utilising the cues to guide attention (in the Mostly Predictive block) can help to reduce or overcome distraction caused by the singleton distracter. If top-down control can reduce distraction caused by the singleton distracter, we expect that participants will experience less distraction on valid trials compared to neutral and invalid trials. We would also predict that top-down cue-utilisation will lead to more distraction on invalid trials compared to neutral trials. We predict that young adults may be able to use top-down control to reduce distraction by the singleton-distracter. According to past research (Iarocci, Enns, Randolph & Burack, 2009), 9-11-year-olds may be able to reduce distraction but not as much as young adults. Lastly, older adults may have retained the ability to use top-down control to reduce distraction (similarly to young adults) or this ability has declined and distraction is not controlled.

Dependent variable. Describe the key dependent variable(s) specifying how they will be measured. (optional)

In the cued visual search task, participants will be asked to search for a white tilted-line target and respond to its orientation (L/R) via keyboard buttons (“z” and “/” keys) as fast and accurately as they can. In the AX-CPT, participants will be asked to press the green button (with their dominant hand) if they see the sequential presentation of a cartoon picture of a hen followed by a cat (AX trial). And to press the red button (with their non-dominant hand) for all other animal pairs (AY, BX & BY trials) as fast and accurately as they can using the same keys specified in the cued visual search task. Each participants' average median response times when they made an accurate response (in seconds) and mean accuracy (%) will be measured for both the cued visual search task and the AX-CPT.

In the AX-CPT we will also compute Proactive Behavioural Index ((AY – BX) / (AY + BX)) for average median response times and mean accuracy for each participant. Positive scores represent greater interference on AY trials (indicator of top-down or proactive control) and negative scores represent greater interference on BX trials (indicator of bottom-up or reactive control). In the cued visual search task, we will calculate cueing ratio scores (invalid / valid) for average median response times and mean accuracy (valid / invalid) for each participant. Values which are greater than 1 represent cue-utilisation (top-down or proactive control) and values less than or equal to 1 represent a *lack of* cue-utilisation (bottom-up or reactive control).

As a control measure, we will ask participants to complete a short colour categorisation task. It is known that some colours often appear similar to categorically different colours (e.g. blue and green; Daoutis, Pilling & Davies, 2006). In the cued visual search task, a coloured cue (e.g. green cue) may appear similar to a different coloured circle in the search-display (e.g. green circle); in this regard, colour cueing to a categorically different colour may have occurred in this task. To control for individual differences in colour similarities in the cued visual search task, we will measure participants' responses to colours gradually ranging from one colour to a different colour (e.g. blue and green). Participants will be asked to complete an alternative forced choice task where they must decide if a coloured circle appears more like one colour or more like a different colour and make a response via keyboard press. In a block, the coloured circle will gradually change from one colour to a different colour. For instance, from 100% blue to 100% green (0%

blue). The colours at both ends of the spectrum will match the colour presented in the cued visual search task. Participants will be asked to complete six blocks of trials where colours gradually change from: blue to green, blue to pink, blue to yellow, green to pink, green to yellow and pink to yellow. The data collected from this task will be used as a control measure to account for individual differences in colour cueing effects.

In the colour categorisation task, participants will be asked to categorise each coloured circle into one of two colour categories (e.g. blue or green). For each condition where one colour changes to a categorically different colour (e.g. 100% blue gradually changes to 100% green), the slope ($(y_1 – y_2) / (x_1 – x_2)$) will be calculated to assess whether participants' perception of colours ranging from, for example blue to green, was a gradual (i.e. GGBGBGBB) or steep change (i.e. GGGGBBBB). A composite slope score will be calculated by averaging the slope values for all six conditions; this composite slope score will be used as the control measure for individual differences in colour cueing effects.

Conditions. How many and which conditions will participants be assigned to? (optional)

Age Group will be a between-subjects condition in this study (5 levels: 5-6, 7-8, 9-11, 18-25 & 60+ years). Participants will be asked to complete: 1) the colour categorisation task, 2) the cued visual search task (which has two block conditions – the Mostly Predictive block and the Baseline block) and 3) the AX-CPT (which has one block of trials). Participants will be asked to complete the colour categorisation task first. The order of the cued visual search block conditions and the AX-CPT will be counterbalanced.

Analyses. Specify exactly which analyses you will conduct to examine the main question/hypothesis. (optional)

Data Transformation:

We will use median response times (s) and mean accuracy (%) to calculate ratio or index scores for each participant. For the cued visual search task we will calculate 1) cueing ratio scores (RTs: invalid / valid; accuracy: valid / invalid) and 2) distraction ratio scores (RTs: singleton-present / singleton - absent; accuracy: singleton -absent / singleton -present). For the AX-CPT, we will calculate Proactive Behavioural Index scores ((AY – BX) / (AY + BX)) for median responses times and mean accuracy.

Aim 1: To understand the development of top-down control across the lifespan.

Cued Visual Search Task:

We aim to compare valid and invalid trials in the Mostly Predictive block to neutral trials in the Baseline block. To perform these comparisons, we will assign “valid” and “invalid” variable names to all neutral trials in the Baseline block. This will be actioned by matching the valid and invalid assignment of trials in the Baseline block to trials in the Mostly Predictive block. We will then calculate cueing ratios for singleton-absent trials (in order to assess cue-use in the absence of the singleton-distracter) using median response times (in seconds) and mean accuracy (%) for each participant. We will conduct a mixed 2(Block: Mostly Predictive block, Baseline block) x 5(Age Group) Analysis of Variance on average cueing ratios for both response times and accuracy.

We predict that top-down control develops gradually across the lifespan. Therefore, we expect to find a significant Block x Age-Group interaction. This is predicted to show that cueing ratios in the Mostly Predictive block will non-significantly differ from the Baseline block for 5-6-year-olds. In contrast, cueing ratios in the Mostly Predictive block are expected to be significantly greater than Baseline for 7-8, 9-11-year-olds and young adults. If top-down control is retained in seniority, we would expect older adults to display a similar pattern of results to young adults. In contrast, others argue that top-down control declines in old age, and so we would then expect a non-significant difference in cueing ratios between the Mostly Predictive and Baseline blocks in older adults.

AX-Continuous Performance Task:

We will conduct a between-subjects one-way Analysis of Variance on proactive behavioural index scores between Age Groups to assess for a main effect of Age Group. Linear and quadratic trend contrasts between age-groups will be conducted. We expect to find a similar pattern of results to the cued visual search task. A significant main effect of Age-Group is expected to show proactive behavioural index scores to significantly increase with increasing age. Older adults however, may show a non-significant difference in index scores to young adults (top-down control is retained) or significantly less in index scores to young adults (top-down control declines).

Aim 2: To understand whether top-down cue-utilisation reduces attentional capture across the lifespan

We will calculate distraction ratios using median response times (in seconds) and mean accuracy (%) for each participant. We will conduct a mixed 2 (Block: Mostly Predictive, Baseline) x 2 (Cue Validity: valid, invalid) x 5 (Age Group) Analysis of Variance on distraction ratios for both response times and accuracy.

If top-down control can reduce distraction, we predict a significant Block x Cue Validity x Age-Group interaction. This is expected to show young adults to have significantly smaller distraction ratios on valid trials in the Mostly Predictive block compared to the Baseline block. If 9-11-year-olds have attained an “adult-like” top-down control they may also show a similar difference as described above to young adults. We would also expect this finding for older adults if they have retained top-down control. Else we would expect older adults as well as 5-6 and 7-8-year-olds to show a non-significant difference between the Mostly Predictive block and the Baseline block for their distraction ratios on valid trials.

For all Analyses of Variance conducted, if Mauchly's test of Sphericity is violated ($p < .01$), we will use Greenhouse Geisser correction to reduce the likelihood of making a type I error. For all analyses, if a significant main effect and/or interaction is found, tests of simple main effects with Bonferroni correction will be conducted.

Aim 3: To understand whether cue-utilisation in the Cued Visual Search task and AX-Continuous Performance Task develops similarly or differently across the lifespan.

A hierarchical multiple regression analysis will be conducted. To test whether the assumptions of this analysis have been met, we will run tests for:

1) multicollinearity (VIF scores must be < 10 and tolerance scores must be > 0.1) – if this criteria is not met, we must look at Pearson correlation coefficients between all predictor variables and consider removing highly correlated variables (where $r = .9$ or above).
2) Singularity – any Pearson correlation coefficients between predictor variables where $r = .9$ or above should be considered for whether they should be removed, amalgamated or are expected to be highly correlated.
3) Deviations from normality, homoscedasticity, independence of residuals – we will conduct a P-P plot on standardised residuals (we expect a small amount of deviation from the expected normality line); a histogram will be conducted for standardised residuals to check they follow a normal distribution; a scatterplot which plots standardised residuals against standardised predicted values in the regression will test for homoscedasticity (if the points do not "funnel out" and do not show large deviations in some areas but not others, we assume homoscedasticity). If the assumptions are not met here, we should consider using a different method for transforming our data.

To understand whether age moderates the relationship between cue-utilisation in the cued visual search task and the AX-CPT, we will need to create dummy variables. These dummy variables will enable us to make comparisons between different age-groups in this analysis. For our aim, we plan to compare 1) five- to six-year-olds vs seven- to eight-year-olds, 2) nine- to 11-year-olds vs young adults and 3) young adults vs older adults. We will create our three dummy variables by assigning weights (0, 1 & -1) to the data (e.g. for our third dummy variable: young adults will be assigned a weight of 1 vs older adults who will be assigned a weight of -1 and all other age-groups assigned a weight of 0). We will create our interaction terms (to assess whether age is a moderator) by multiplying each dummy variable by the proactive behavioural index score for each participant; resulting in three interaction terms: 1) five vs seven x PBI, 2) nine vs young adult x PBI and 3) young adult vs older adult x PBI.

The outcome variable will be average cueing ratios on singleton-absent trials in the Mostly Predictive block of the cued visual search task. There will be two models inputted into the analysis. Model 1 will include six predictor variables: 1) proactive behavioural index scores in the AX-CPT, 2) average colour categorisation slopes (calculated by averaging the slope scores across all six colour category block conditions), 3) age, 4) five vs seven dummy, 5) nine vs young adult dummy and 6) young adult vs older adult dummy. Model 2 will input three additional predictor variables which will be interaction terms: 1) five vs seven x PBI, 2) nine vs young adult x PBI and 3) young adult vs older adult x PBI. Therefore, Model 2 will now have a total of nine predictor variables. These interaction terms will be formed by creating dummy variables for each of the bracketed age-groups above to be compared. For each model, an ANOVA will test the fit of the model by assessing whether the R-squared predicts a significant proportion of the variance in the outcome variable. We will also assess R-square change between Model 1 and Model 2 using an ANOVA. To assess which predictor within each model contributed the most for explaining the variance in the outcome variable, we will conduct one-sample t-tests to test whether the predictor’s contribution is significantly greater than 0. Standardised beta values will be used to understand the direction of the relation between the predictor variable and the outcome variable.

To further understand the direction of any significant predictor, will will conduct Pearsons' Correlation Coefficients between cueing ratios on singleton-absent trials in the Mostly Predictive block and proactive behavioural index scores for each age-group.

We predict that cue-utilisation in the AX-CPT (controlling for colour differences and age; Model 1) will account for a significant proportion of the variance in the Mostly Predictive block of the cued visual search. We also expect that including the age interaction terms as moderators in this prediction (Model 2) will lead to a significantly greater proportion of variance in the outcome variable to be explained by the model. For each model we expect proactive behavioural index scores to be the best predictor of cue-utilisation in the Mostly Predictive cued visual search task, with increases in index scores to predict increases in cueing ratios.

Outliers and Exclusions. Describe exactly how outliers will be defined and handled, and your precise rule(s) for excluding observations.(optional)

The first trial as well as the first trial following a break period will be removed from the data. During both cognitive tasks, each participant's average response time + 4 standard deviations in the previous blocks of trials will be calculated. Response times which are longer than this deadline will be timed out and participants will be presented with a ticking clock image to remind them to respond as fast and accurately as they can. For the cued visual search task, we will exclude trials where the singleton distracter was located within the same quadrant (quarter of the screen) as the target line. As a pilot study found that these trials significantly slowed search times which suggests that these trials tap into a process which is not of interest in this study.

We will assess our data for multivariate outliers by conducting three Mahalanobis Distance assessments for all participants in each age-group. We will calculate a Mahalanobis Distance across all response time and accuracy variables in: 1) the cued visual search task, 2) the AX-CPT and 3) across all variables to be entered in the multiple regression analysis. If a participant's cumulative probability for their Mahalanobis Distance in any one of the three analyses is greater than .001, they will be excluded from *all* further analyses. This will ensure that our dataset contains the same set of participants in all analyses conducted.

Participants who have a formal diagnosis of: colour blindness, visual impairment (i.e. floaters, partial vision), Autistic Spectrum Disorder and/or Attention Deficit and Hyperactivity Disorder will be excluded from the analysis. If a participant fails to complete all of the within-subject conditions, they will be excluded from the analysis. In both the cued visual search task and AX-CPT, if a participant makes three incorrect responses in a practice stage and continues to do so after three repeat attempts at the practice trials, they will be thanked for taking part and their data will be excluded from the analysis (on account of failure to understand the instructions/buttons).

Sample Size. How many observations will be collected or what will determine sample size? No need to justify decision, but be precise about exactly how the number will be determined.(optional)

A power analysis has been conducted using g*power (Faul, Erdfelder, Buchner & Lang, 2009) to assess the number of participants required to attain a power of .9 at an alpha criterion of .01 for a multiple regression R-squared to deviate from 0. This model will contain nine predictor variables (Model 2: proactive behavioural index + average colour category slope + age + five vs seven dummy + nine vs young adult dummy + young adult vs older adult dummy + five vs seven x PBI + nine vs young adult x PBI + young adult vs older adult x PBI interaction terms). We powered for a small to medium effect size (cohen's f^2 = .1), as past research has found that an alternative task of proactive control (Track-It paradigm) significantly predicted the proactive behavioural index in a child-adapted version of the AX-CPT (Doebel et al., 2017: accuracy comparison – medium effect size $\eta_p^2 = .11$; response time comparison – small effect size $\eta_p^2 = .04$). Our power analysis found that a total of 273 participants are required to attain a power of .9 at an alpha criterion of .01 for a small to medium effect size. This results in the requirement of 54-55 participants per age-group. For order counterbalancing purposes, our stopping rule will maintain that we recruit a maximum of 66 participants per age-group.

Other. Anything else you would like to pre-register? (e.g., secondary analyses, variables collected for exploratory purposes, unusual analyses planned?)(optional)

Data has been partially collected for 18-25-year-olds and 60+ years age-groups only. The data has not been accessed or looked at by any principal investigators in any way. Data collection for 5-6-, 7-8- and 9-11-year-olds is still ongoing.

Name. Give a title for this AsPredicted pre-registration. Suggestion: use the name of the project, followed by study description.(optional)

The Development of Top-Down Control: A Comparison of the Cued Visual Search and AX-Continuous Performance Task Across the Lifespan

Appendix 6.2. Colour Categorisation Task: Interval and Named Colours

In the Colour Categorisation task there were six block conditions where colours ranged from one experimental colour (e.g. blue) to another experimental colour (e.g. green). The RGB colour scale was used to manipulate the hue of the coloured circle on each trial. In each block condition, the difference between one experimental colour's and the other experimental colour's RGB values was calculated and divided by 10 to create a gradual shift between the colours. *Table 6.2.1* shows the increments and decrements to the RGB values to create each of the interval colours in each block condition. To reinstate, this task was concerned with gradually changing the hue from one experimental colour to another; comparisons between block conditions were not made. The trials in each block condition were randomly presented to participants.

Table 6.2.1. Increments (+) and decrements (-) in RGB (red, green, blue) colour channels on each trial within the six block conditions.

	R	G	B
Blue to green	-.0228	+.015	-.0935
Blue to pink	+.07138	-.03266	-.0321
Pink to green	-.09418	+.04766	-.0614
Yellow to blue	-.076138	+.00045	+.08685
Yellow to green	-.09849	+.01545	-.00665
Yellow to pink	-.00431	-.03221	+.05475

In the task, participants were instructed that if they did not feel the coloured circle fit into either one of the two supplied categories, they could name the colour category they thought it looked more similar to. *Table 6.2.2* (*see overleaf*) provides frequencies for the named categories. Some of the named categories were recoded according to Kelly and Judd (1955) and Mojsilovic (2004). Others were not recoded as they were defined as their own colour category.

Table 6.2.2. Number of times where named colours were either recoded into the existing categories (in brackets) or were not recoded as they are defined as their own category.

Recoded		Neither Category – Not Recoded	
Beige (yellow)	25	Grey	286
Turquoise (blue)	4	Orange	176
Amber (yellow)	4	Purple	158
Gold (yellow)	1	Brown	111
Mustard (yellow)	1	Red	14
Sand (yellow)	1	Mauve	11
Nude (yellow)	1	Lilac	3

Appendix 6.3. Colour Categorisation Task: Descriptive Statistics for Colour Slope Scores

The descriptive statistics for the slope scores in each of the six block conditions are highlighted in *Table 6.3.1*. The maximum slope score which can be attained in each block condition is .30. From inspecting the standard deviations, this might suggest that the variability between the conditions and age-groups were similar to one another. This could suggest that participants did not have less discriminability in one colour block condition relative to others. Inspection of the means suggests that all participants were responding close to ceiling in this task. This could suggest that this measure is subject to ceiling effects, which influences its sensitivity as a colour discriminability measure.

Table 6.3.1. Means and standard deviations of colour slope scores in each block condition for Young and Older Adults.

	Young Adults		*Older Adults*	
	M	*SD*	*M*	*SD*
Blue to green	.29	.02	.29	.02
Blue to pink	.29	.02	.29	.02
Pink to green	.30	.01	.30	.01
Yellow to blue	.27	.04	.26	.05
Yellow to green	.23	.08	.24	.05
Yellow to pink	.26	.03	.25	.06

Note: M = mean; SD = standard deviation.

Appendix 7.1. Pre-registration for the main hypotheses and analyses in Chapter 7

The pre-registration for Chapter 7 was uploaded to the Open Science Framework: Hayre, R. K., Cragg, L., & Allen, H. A. (2020, May 12). The Influence of Search Strategy on Cue-Utilisation and Distracter-Suppression in the Cued Visual Search Task. Retrieved from osf.io/hnsjb.

Data collection. Have any data been collected for this study already? (optional)

Please choose. Note: 'Yes' is a discouraged answer for this preregistration form.

Yes, we already collected the data.

No, no data have been collected for this study yet.

X It's complicated. We have already collected some data but explain in Question 8 why readers may consider this a valid pre-registration nevertheless.

Hypothesis. What's the main question being asked or hypothesis being tested in this study? (optional)

This study aims to understand the influence of search strategies on cue-utilisation. Several approaches to understanding visual search and attention have proposed two distinct modes when asked to find a target item. On the one hand there is an automatic, process and on the other hand there is an active, directed 'top-down' process. For example Leber and Egeth (2006) proposed that we can search for a target using two different strategies. The singleton detection mode is a bottom-up process as it depends on searching for a target based on its uniqueness in the search-display (e.g. a red item amongst green items), as research has found that search is faster and more accurate when the target is the "odd" or unique item in the search-display relative to when it is not (Gaspelin et al., 2015). The conjunction search mode is a top-down process as it requires participants to maintain the goal to search for a particular target (e.g. a red square) before they see it, which guides their attention towards this item in the search-display (e.g. a red square amongst different shapes and colour non-target items). Some research suggests that we are more vulnerable of being distracted by an irrelevant and unique distracter in the search-display if we are using a singleton detection mode to locate the target (Gaspelin et al., 2015; Sawaki & Luck, 2013).

Even if participants are instructed to search for a particular target (to encourage them to use a conjunction search mode), if that target is a unique item in the search-display participants will likely use a singleton detection mode (Gaspelin et al., 2017). This more automatic mode is less demanding on early processes; thus resulting in a higher likelihood of being distracted by an eye-catching item. Research has suggested that we can encourage participants to utilise a conjunction search mode by varying the non-target items in the search-display to ensure that the target is not a singleton (e.g. a red square target presented amongst non-target items which share a feature of the target; Zhuang & Papathomas, 2011).

This study will use a cued visual search task. Participants will be presented with a search-display which contains three coloured circles. The target line will be located within one of the circles and two non-target lines will be located within the remaining circles. Prior to the search-display, participants will see a ‘cue’ which may be *valid* (matches the colour of the circle containing the target), *invalid* (colour mismatches the colour of the circle containing the target) or *neutral* (a colour not presented in the search display).

Participants will be asked to complete two blocks of trials. There will be a Mostly Predictive block where 66.67% of the cues are valid in guiding attention towards the cue (and 33.33% of cues are invalid as they guide attention away) and a Baseline block where 100% of the cues are neutral and do not guide attention. In both blocks, a singleton distracter (a black diamond) will be presented on 41.67% of trials to measure distraction caused by a salient but irrelevant item when it is present in the search-display relative to when it is absent.

Half the participants will search for a (45 degree) tilted white line target which will be presented amongst vertical white line non-target items (‘Easy search group’). The target will be a unique item in a homogeneous set of non-target items and thus should lead to singleton, or bottom up driven search processes. The remaining participants will search for a tilted white exclamation point (!; either 45 degrees clockwise/anti-clockwise) which will be presented amongst a heterogeneous display of ‘i’ items (‘Difficult search group’). In this case the target is not a singleton in the orientation dimension as it will be presented amongst non-target items which are also tilted (ensuring that the target does not ‘pop out’). This meets the criteria for encouraging a conjunction (top-down) search mode. With this method we ask two main questions:

Research Question 1: Does a conjunction search mode encourage greater cue-utilisation compared to a singleton detection mode?

It is possible that using a singleton detection mode means participants are less encouraged to utilise cues to locate a target as they can find the target that is unique in the search-display (Gaspelin et al., 2015). In contrast, a conjunction search mode may encourage participants to utilise the cues to help them make anticipatory responses to a nonsingleton target which is difficult to find (Bacon & Egeth, 1994; Gaspelin et al., 2017). **We predict that participants in the ‘Difficult Search’ group will benefit more from valid cues in the Mostly Predictive block compared to participants in the ‘Easy Search’ group.**

Research Question 2: Does a conjunction search mode reduce or prevent distraction caused by a singleton-distracter more than a singleton detection mode?

Research has shown that encouraging participants to use a conjunction search mode prevents participants from being overtly distracted by a salient distracter (Gaspelin et al., 2017; Sawaki & Luck, 2010). We ask how distraction acts when participants are provided with information about the upcoming target on a trial-by-trial basis. We argue that if a conjunction search mode enhances attention towards the cued location of the target, this attentional set can be used to inhibit attention directed towards a singleton-distracter. In contrast, a singleton detection mode encourages participants to search for singleton items which is argued to make them vulnerable to being distracted by an irrelevant singleton-distracter (Gaspelin et al., 2015). If this is the case, **we predict that participants in the Difficult search group will experience less distraction on valid trials in the Mostly Predictive block, relative to the Baseline block as well as relative to participants in the Easy search group.**

Dependent variable. Describe the key dependent variable(s) specifying how they will be measured. (optional)

Participants will be asked to respond to the orientation (L/R) of the target via keyboard press as fast and accurately as they can. Participants accuracy (%) and median response times (in seconds) where they made an accurate response will be analysed. We will calculate cue-utilisation scores (invalid median response time / valid median response time; valid mean accuracy / invalid mean accuracy). A cueing ratio which is greater than 1 suggests a high level of cue-utilisation. Distraction by the singleton distracter will be calculated as a ratio (distracter-present median response time / distracter-absent median response time; distracter-absent mean accuracy / distracter-present mean accuracy). A distraction ratio greater than 1, suggests a high level of distraction caused by the singleton distracter.

Conditions. How many and which conditions will participants be assigned to? (optional)

There is one between-subjects variable in this study (Group; 2 levels: Easy search, Difficult search). All participants will be asked to complete both within-subject block conditions (Block Predictiveness; 2 levels: Mostly Predictive block, Baseline block). The order of each block condition will be counterbalanced for each group. Within the block conditions, participants will be presented with either a valid, invalid or neutral cue which guides their attention. All participants will perform trials with, and without a singleton distracter, giving the Distracter-Presence factor (2 levels: distracter-absent, distracter-present).

Analyses. Specify exactly which analyses you will conduct to examine the main question/hypothesis. (optional)

Research Question 1: Does a conjunction search mode encourage greater cue-utilisation compared to a singleton detection mode?

We aim to compare cue-utilisation (valid vs invalid) in the Mostly Predictive block to performance in the Baseline block for the Easy Search group and the Difficult Search group.

To perform these comparisons, we will assign “valid” and “invalid” variable names to all neutral trials in the Baseline block. This will be actioned by matching the valid and invalid assignment of trials in the Baseline block to trials in the Mostly Predictive block. We will then calculate cueing ratios (see above).

We will conduct a Group (Easy Search, Difficult Search) x Distracter-Presence (distracter-absent, distracter-present) x Block Predictiveness (Mostly-Predictive, Baseline) mixed Analysis of Variance (ANOVA) on average cueing ratios.

We predict that both groups will have greater cue-utilisation in the Mostly-Predictive block relative to the Baseline block (main effect of block predictiveness). We predict that a conjunction search mode will lead to greater cue-utilisation than a singleton detection mode. Therefore, we expect to find a significant Group x Block Predictiveness interaction. **We expect that**

the Difficult Search group will have greater cue-utilisation in the Mostly Predictive block than the Easy Search group. Cueing ratios in the Baseline block are not expected to significantly differ between groups.

Research Question 2: Does a conjunction search mode reduce or prevent distraction caused by a singleton-distracter more than a singleton detection mode?

To measure distraction, we will calculate distraction ratios (see above, singleton distracter present vs singleton distracter absent). We will conduct a Group (Easy Search, Difficult Search) x Cue Validity (valid, invalid) x Block Predictiveness (Mostly-Predictive, Baseline) mixed ANOVA on average distraction ratios.

We predict that participants using a conjunction search mode will experience less distraction on valid trials in the Mostly Predictive block relative to participants using a singleton detection mode. Therefore, we expect to find a significant Group x Cue Validity x Block Predictiveness interaction. **This is expected to show that participants in the Difficult Search group will have significantly smaller distraction ratios on valid trials in the Mostly-Predictive block relative to the Baseline block as well as relative to participants in the Easy Search group.**

For all analyses, if we find a significant interaction we will use simple main effects analysis with Bonferroni correction to further assess the finding. We will use an alpha criterion where p must be less than .01 in order to report that the result is significant.

Outliers and Exclusions. Describe exactly how outliers will be defined and handled, and your precise rule(s) for excluding observations.(optional)

The first trial of each block of trials as well as the first trial following a break interval (3 per block) will be removed from the analysis. Each participant's average response time + 4 standard deviations in the previous blocks of trials will be calculated. Response times which are longer than this deadline will be timed out and participants will be presented with a ticking clock image to remind them to respond as fast and accurately as they can. We will remove trials where the singleton-distracter was presented in the same quadrant (quarter of the screen) as the target. A pilot study found that these trials led to poorer accuracy which suggests that these trials tap into a process which is not of interest in this study. Inaccurate trials will not be included in our analysis of response times.

To assess whether there are multivariate outliers in the dataset, Mahalanobis Distance will be calculated for each participant across all response time and accuracy data. If a participant's Mahalanobis distance value is less than a cumulative probability of 0.001, they will be classed as a significant multivariate outlier and will be removed from further analysis.

If a participant fails to complete all of the block conditions and/or has reported to have had a formal diagnosis of Autistic Spectrum Disorder, Attention Deficit and Hyperactivity Disorder and/or a visual impairment (partial vision, colour blindness, visual floaters), their data will not be included in the analysis. If a participant has had three repeat attempts at any one of the practice phases and has continued to make three or more response errors, the researcher will stop the experiment and thank the participant for their time.

Sample Size. How many observations will be collected or what will determine sample size? No need to justify decision, but be precise about exactly how the number will be determined.(optional)

This study was carried out as part of a wider study (The Development of Top-Down Control: A Comparison of the Cued Visual Search and AX-Continuous Performance Task Across the Lifespan). As well as completing the cued visual search task, this study asked participants in the Easy Search group to complete a different cognitive task (AX-Continuous Performance Task). We conducted a power analysis for this study based on past research and found that we required 54-55 participants per age-group (five age-groups) to acquire a power of .9 at an alpha criterion of .01. On this basis, we will aim to acquire 54-55 participants per group for the current study which is above the sample size from previous research in this area.

Other. Anything else you would like to pre-register? (e.g., secondary analyses, variables collected for exploratory purposes, unusual analyses planned?)(optional)

Data collection for participants in both groups has already begun and is still ongoing. This study is part of a third-year psychology undergraduate student project. Data has not been accessed or looked at by any principal investigators in any way.

Name. Give a title for this AsPredicted pre-registration. Suggestion: use the name of the project, followed by study description.(optional)

The Influence of Search Strategy on Cue-Utilisation and Distracter-Suppression in the Cued Visual Search Task