EVALUATING STRATEGIES FOR VISUAL SEARCH AND STIMULUS DISCRIMINATION: IMPLICATIONS FOR TRAINING EYE-MOVEMENTS

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Abstract

Eight experiments are described which explore the consequences of training eye-movements. Training is related to Findlay & Walker's (1999) model of saccade generation, and consists of different strategies for visual search and stimulus discrimination. These two components are separated herein, in an effort to link training to the hypothesised Move and Fixate centres, respectively, within the framework proposed by Findlay & Walker. Training directed towards the Move centre thus consistently improved visual search, and in Experiments 1-4 it was also shown that training directed towards the Fixate centre could further improve performance (in terms of target response discrimination) in an additive way over Move Training alone. Experiments 5-7 specifically investigated the idea that eye movement training which promotes activity in the Move centre, independently, may actually be detrimental. This hypothesis draws upon the reciprocal inhibitory relationship between the Move and Fixate centres described by Findlay & Walker: training people *where* to look may increase activity in the Move centre and consequently hinder information processing during fixational eye movements, owing to an associated diminution of activity in the Fixate centre. Partial support for this conclusion was found. When training encouraged saccades away from a task-relevant centrally located stimulus, towards a visible saccade target in the periphery, there was evidence of premature disengagement when fixating, causing sub-optimal processing of the central stimulus in the first instance (Exp. 5). However, this effect was sensitive to changes in task. It may be possible to adapt eye-movement control to task demands, and counter Move–Fixate competition via volitional mechanisms (Exp. 6). Furthermore, it appears that the combination of top down training *and* bottom up activation from stimuli is necessary to impede performance when training

is isolated to the Move centre (Exp. 7). These factors may explain why Move training did not encumber performance in a driving task (Exp. 8). Nevertheless, the findings reported in this thesis have implications for training eye-movements in applied settings, because they suggest that domain specific experts should focus *both* upon eye-*movements* (i.e. Move training), *and* information acquisition during fixations (i.e. Fixate training) when developing visual training regimes for 'real-world' contexts. Combined eye movement training directed towards the Move and Fixate centres in concert may produce cumulative performance gains, and offset detection failures associated with Move training alone, consistent with the general pattern of results presented.

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Contents

1. Chapter I – General Introduction

1.1. Overview

A central focus of vision research in recent decades has been to identify what visual search strategies people use in different contexts. Recent models of visual attention (Logan, 1996) and eye movements (Findlay & Walker, 1999; Itti & Koch, 2000) have been primarily concerned with the bottom-up influences of stimuli, via saliency maps, upon the decision to fixate a stimulus or to make a saccade to another stimulus. It is less clear however, how goal directed strategies effect eye movements via top-down control. While research into the top down guidance of eye movements is not new (e.g. see the seminal studies of Yarbus, 1967), there remains much we still do not fully understand. In particular, how do eye movements change when implementing visual training strategies which rely on voluntary control? This is the focus of the research to be presented. Using Findlay & Walker's (1999) model of saccadic eye-movements as a basis, specific strategies to enhance the efficiency of participants' visual search have been developed. These "training" principles are purposefully designed to reduce response times to target stimuli via two routes in Findlay & Walker's model. It will be argued that top-down control strategies can differentially affect the WHERE and WHEN pathways of Findlay & Walker's model, and that training can be directed to these pathways either independently or in concert, with different consequences. This research is particularly relevant to training the eye-movements of novice practitioners of complex tasks (e.g. learner drivers), where there has been mixed success in the literature to date.

This chapter reviews the literature relating to this topic, beginning with coverage of some of the most well known theoretical accounts of eye movements and attention. Findlay & Walker's (1999) model is outlined first, and in somewhat greater detail than the other theories considered. I will explain why Findlay & Walker's model was chosen over others as the framework upon which to base this thesis, hence justifying its extended coverage.

As training eye movements is central to the thesis I will critique this area of research with the aim of highlighting that there has been mixed success in attempts to train eye movements. None of the studies which employ eye movement training however approach the issue from the dual process perspective outlined in Findlay & Walker's model, and I argue that this would beneficial. This chapter ends therefore with a summary of the experiments conducted for this thesis based upon Findlay & Walker's framework.

1.2. Models of visual attention and eye movements

Findlay & Walker (1999): Model Details

Findlay & Walker's (1999) model of saccade generation provides a framework for predicting WHEN the eyes will move and WHERE they will move to. The model organises eye movement control into a hierarchical representation of the descending pathways in vision (Fig. 1.1). Eye-movements are assumed to be regulated by relatively automatic processes such as stimulus salience, and the proximity of visual events to the point of current fixation. Stimuli compete for attention via reciprocal inhibition between a Fixate centre (regulated by the WHEN pathway) and a Move centre (regulated by the WHERE pathway), and an eye-movement is triggered when an extrafoveal location generates more activity in the Move centre than the activity in the Fixate centre representing the current locus of attention.

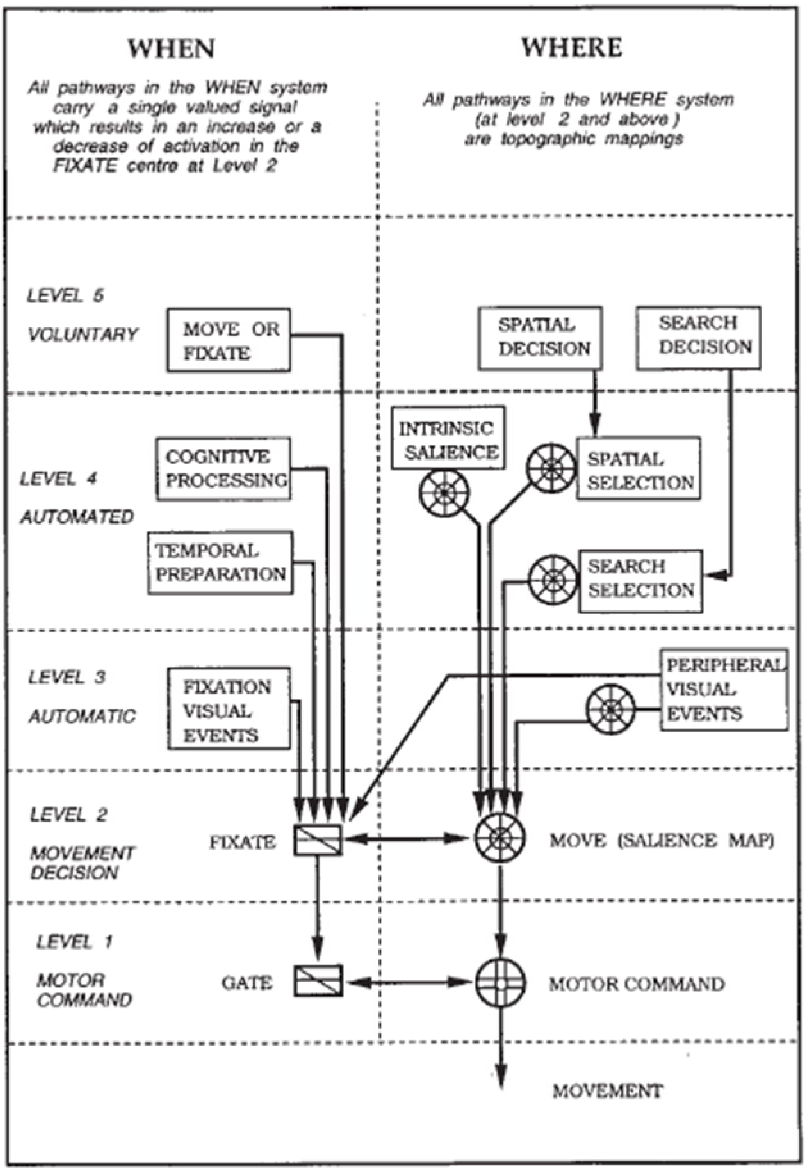

Fig. 1.1. Diagram indicating the information flow routes and competitive pathways in saccade generation (taken from Findlay & Walker, 1999).

Level 1 of the model refers to the motor command to trigger an eye-movement. The gate in level 1 of the WHEN pathway will remain closed if the activation it receives from descending pathways is maximal, in which case a motor command to initiate a new saccade will not be sent. If however, activation in the fixate gate is minimal in comparison to that of level 1 in the WHERE centre, a motor program will be delivered to the occulomotor muscles specifying the spatial metrics of the saccade determined by input from the WHERE pathway. Level 1 processes are ballistic, reflecting the basic physiology and musculature of the visual system.

Anatomically the 'push-pull' competition at level 1 occurs in the brain-stem. In terms of the WHEN pathway Omnipause cells, which normally fire at a high rate when fixation is maintained, cease firing between 5-15ms before a saccade and do not resume firing until after the saccade has been executed. The opposite pattern of activity is evident in Burst cells of the brain-stem; these cells increase their rate of firing substantially while a saccade is in progress. The WHEN and WHERE terminology is appropriate to describe these low-level competitive interactions, especially because the activity of omnipause cells shows no specificity in terms of spatial metrics whereas that of burst-cells does (see Wurtz & Goldberg, 1989, for a review of this background on oculomotor physiology).

The basis in oculomotor physiology and brain stem circuitry supports the connection proposed between the fixation gate at level 2 of the WHEN and the omnipause cells at level 1. The term "fixation gate" refers to the rostral pole region of the superior colliculus. This brain area is sensitive to Gamma-Amino Butyric Acid (GABA): in monkeys the injection of the GABA agonist muscimol into the rostral pole leads to gross difficulties in maintaining fixation; whilst injection of the GABA antagonist bicuculline reduces saccadic activity. Therefore researchers have suggested that the neural representation of the fovea carried by the rostral pole reveals a gating mechanism which regulates how long fixation is maintained (Munoz & Wurtz, 1993).

Whereas the fixation gate in the WHEN pathway is concerned with the temporal component of disengaging fixation, level 2 of the WHERE pathway contains a saliency map which codes the landing point of the next saccade in a “winner-take-all” fashion. Coding here is spatially distributed with a single location being selected quickly and in parallel. This ensures that competition between two (or more) potential saccade landing points is resolved and that the saccade destination selected is that of maximum salience when summed over potential locations in the visual field. Evidence for conflict resolution in terms of a smooth saliency landscape, generated by divergent and overlapping receptive fields, is available with reference to the Global Effect. Here, when two potential saccadic targets are spatially separated yet in reasonably close proximity, the initial saccade made towards them is reliably found to land at an intermediate position between their locations. The relative saliency at the saccadic landing point may be quantified on the basis of stimulus properties such as size, luminance, spatial frequency, and possibly colour (Deubel, Wolf, & Hauske, 1984; Irwin, Colcombe, Kramer, & Hahn, 2000; Moore, Lanagan-Leitzel, Chen, Halterman, & Fine, 2007).

However, how do competitive interactions within the saliency map evolve? Tenable evidence is available from monkey physiology. Schlag-Ray, Schlag, & Dassonville (1992) have demonstrated that when electrical stimulation is delivered to the Frontal Eye-Fields (FEF) thus invoking a saccade, activation is found in intermediate layers of the superior colliculus, outside the rostral pole which controls the fixation gating mechanism outlined above. This activation corresponds to the direction of the elicited eye-movement and may be contrasted with surrounding suppression in movement fields which do not correspond to the direction of the saccade. The same principle of activation and inhibition may apply to target search. Neurons which selectively respond to the spatial region containing a colour target exhibit an amplification of activity just prior to target directed saccades; this is mirrored by the decline in responsiveness in adjacent neurons which selectively encode spatial areas occupied by distractors (Schall & Hanes, 1993).

Along with this conflict resolution Munoz & Wurtz (1995a; 1995b) also demonstrate how the peak of highest salience may be selected. Throughout the collicular map, with the exception of the rostral pole, are 'build-up' cells and 'burst cells'. The former show a gradual rise in activation levels when a saccade target is presented, whereas the latter elicit a sudden pulse of activity immediately before an eye-movement which differs according to the saccade landing point. Findlay & Walker (1999) argue that the activity of 'build-up' cells reflects the selection of an unequivocal saliency peak, while that of burst cells initiates an eye movement towards the location this peak represents, coding the spatial metrics of the saccade. As well as providing an outline of competitive interactions within the saliency map, evidence from collicular processes provides further support for the push-pull linkage between the WHERE and WHEN pathways: increased activity in build-up cells leads to a reciprocal reduction of activity in fixation cells of the rostral pole, and vice versa.

At level 3 the authors argue that direct visual influences feed into the fixate gate and saliency map affecting the fixate-move balance. In terms of the WHEN pathway foveated stimuli promote continued fixation whereas their offset reduces activity in the fixate gate making a saccade more likely. This finding is nicely shown in 'The Gap Effect'. Here saccade latency (fixation duration preceding a single saccade) to a peripheral target can be seen to decrease when a fixated stimulus is removed from view a little earlier than the target appears (Kingstone & Klein, 1993).

Paradoxically however, visual events at the periphery seem to induce activity in *both* the saliency map of the WHERE pathway *and* the fixate gate of the WHEN pathway. This is evidenced by the 'Remote Distractor Effect', where a distractor which is spatially removed from the target can be seen to increase saccade latencies in a systematic way depending on how proximal or distal it is from the current point of fixation (Walker, Deubel, Schneider, & Findlay, 1997). Near distractors will give rise to a longer delay in saccade triggering, with this effect decreasing in magnitude in a linear fashion as the distractor is presented further away from fixation. As this effect is not due to the distance between target and distractor, yet predictably linked to distractor eccentricity, it necessitates the inclusion of what Findlay & Walker (1999) refer to as a 'non-specific fixate system' in their model.

Recent evidence shows that the combined influences which give rise to the global effect and the remote distractor effect can account for saccadic accuracy. The imprecise 'centre of gravity' fixations indicative of the global effect can be more accurately directed when the visual array contains more distractors (McSorley & Findlay, 2003). These authors suggest that the extension of saccade latencies induced when distractors are more numerous (implicating the non-specific fixate system) gives the visual system adequate time to differentiate between peaks of saliency which initially overlap (ordinarily giving rise to the global effect). At longer temporal delays therefore saliency peaks can be more precisely distinguished as they are based on less coarse averaging, and this results in a diminution of the global effect. This evidence is comparable with the initial emergence of low spatial frequency visual information and the later tuning to high spatial frequency information (Hughes, Nozawa, & Kittlerle, 1996; Unema, Pannasch, Joos, & Velichkovsky, 2005).

As we move further up the hierarchy depicted by the model the processes become more linked with top-down control, although not explicitly so; the focus of the model is still very much the generation of eye-movements due to properties of visual stimuli. At level 4 in the WHERE pathway for example, *search selection* facilitates target search by allowing the location of a predefined target to be enhanced slightly before a saccade. As referenced above when explaining conflict resolution in the saliency map, this boost of neuronal activity occurs for locations containing a target colour and is coupled with reduced activity for locations which contain distractors (Schall & Hanes, 1993). In line with the notion of a spatial saliency map, these neurons [found in monkey FEF] are responsive to locations; therefore it is not the defining colour dimension of the target per se that benefits from visual enhancement, rather the position of the target in *xy* coordinates.

Likewise *spatial selection*, the authors acknowledge, is similar in many ways to the classical analogy of attention as a 'spotlight'(Posner, 1980. Although it is important to note that Findlay & Walker's [1999] model is purposefully set up to avoid such analogies of attention). Spatial selection allows stimuli which are presented within a potentiated spatial window to be processed more efficiently. Conversely, certain locations can also be filtered out certain to aid visual search; as with Inhibition Of Return, where areas which have been previously scanned are momentarily inhibited thus preventing unnecessary saccades to locations already dealt with (Tipper, Weaver, Jerreat, & Burak, 1994).

The final element involved with the WHERE centre at level 4 is *intrinsic salience.* This term has caused some controversy because Findlay & Walker (1999) argue that certain stimuli are more salient than others by default *and* that this intrinsic salience can be accrued via learning. One would not question that stimulus characteristics such as brightness, high-contrast, and luminance are particularly attention-grabbing; however, the suggestion that intrinsic salience can be *learned* is somewhat counter-intuitive, as it implies that the stimulus was not intrinsically salient in the first place. Nevertheless this is a side issue and does not detract from the overall plausibility of the model.

Moving on to level 4 of the WHEN pathway, *cognitive processing* reflects the ability to adapt saccades relative to the information that is acquired when something is fixated. Reading provides a good example. If, when reading, the WHEN pathway did not have access to when a word had been fully processed then the sequencing of fixations maybe too long or too short for reading to occur efficiently. Similarly, *temporal preparation* is characterised by anticipatory saccades and fixations occurring due to factors such as predictable timing of target onset, a warning signal, or higher order knowledge of the temporal sequence of eye-movements that will be necessary for a particular task.

Finally, the details of level 5 processes are quite sparse: we may decide to move our eyes to a particular location (*spatial decision*), influencing the lower level spatial selection process; or we may decide to search for a particular object (*search decision*), influencing the lower level search selection processes. Findlay & Walker (1999) simply comment that *"…*Level 5 reflects the self-evident point that, at least for normal individuals, all lower-level processes can be over-ridden and an individual can either suppress saccades and maintain fixation, or can move the eyes voluntarily*"* (p. 664). Of course this is true; however, one may argue that top-down processes are as intricate and complex as the predominantly bottom-up influences on vision mentioned thus far. Moreover, additional information seems necessary in order to expand Levels 4 and 5 of the model. Findlay & Walker argue that instances of overriding supervisory decisions are rare in the saccadic system. However, while this may be correct from the point of view that active vision does not require one to "decide" to move their eyes, surely the top-down processes involved at Levels 4 and 5 can be utilized to assist visual search if understood more fully? This is where the present research will concentrate, expanding on the understanding of top-down control currently available from Findlay & Walker's model and the related literature.

Logan (1996): CODE Based Theory of Visual Attention

Some have commented that Findlay & Walker's (1999) model, although elegant in accounting for various oculomotor statistics in simple target detection paradigms, is too simplistic because it does not detail how the eyes select stimuli for object recognition –in short, it contains 'where' and 'when' but not 'what' (Doré-Mazars, 1999). The CODE Theory of Visual Attention (Logan, 1996) on the other hand adds to Findlay & Walker's model by accounting for how stimulus identity information is integrated in attentional selection processes. CODE-TVA is an amalgamation of Bundesen's (1990) theory of visual attention and Compton & Logan's (1993) theory of perceptual grouping by proximity. The former allows some specification of 'what' a visual display contains, while the latter deals with spatial localisation (the abbreviation CODE originates from an earlier COntour DEtector theory, see Oeffelen & Vos , 1983).

The identification component of CODE-TVA consists of two processes, one that represents features of display items, and one that calculates category membership of these features allowing perceptual grouping. The greater the sensory evidence that item *x* belongs to category *y* the higher the probability that it will be grouped and identified as such. Again this is determined by the bottom-up quality of what is visually presented. A number of parameters are applied to this function but the take home message is that low level identification is modelled such that stimulus properties like colour, form, and orientation are classified and made available for later scrutiny (note that the 'what' element here is still very simplistic and the object recognition literature provides much more detailed accounts of high level object identification. See Ullman, 1996).

This 'what' information is combined preattentively with 'where' information by way of a saliency map, as in Findlay & Walker's (1999) model . The saliency map thus represents items grouped by proximity and similarity and is referred to by Logan (1996) as the CODE surface. Each item in space is represented in the CODE surface by its own distribution (note that this differs from Findlay & Walker's [1999] concept of a saliency map in that no spatial averaging takes place, and each stimulus has its own isolated saliency peak). Thresholds are applied to these distributions resembling the allocation of top-down attention (Fig. 1.2). Areas above the threshold are called *feature catches* and attentional mechanisms can be applied to them, such as biasing attention towards a particular stimulus in the display or weighting the priority of a particular stimulus categorisation.

The CODE theory of visual attention has close affinities with some of Findlay & Walker's (1999) themes. The spatial and stimulus categorisation aspects of CODE-TVA are not unlike Findlay & Walker's *spatial selection* and *search selection* respectively. Again however, Logan's (1996) theory is underspecified in dealing with the top-down control of attention: it describes in meticulous detail what the top-down allocation of a threshold does (i.e. allowing items above the threshold cut off to be processed as independent objects in separate locations), precisely clarifying how this function can be translated into mathematical formulae. However, as with Findlay & Walker's model, CODE-TVA provides little detail on higher cognitive functions. It does not explain how top-down attentional control can be equated with the threshold, less so how the choice of threshold is determined, with little expansion on the idea postulated that multiple thresholds can be applied simultaneously. Moreover, Logan's theory is purely attentional, therefore makes no claims about eye movements. Some of its principles are important for this thesis, but, without a detailed explanation of how attention translates into eye movements this theory was not used as the framework on which to base eye movement training.

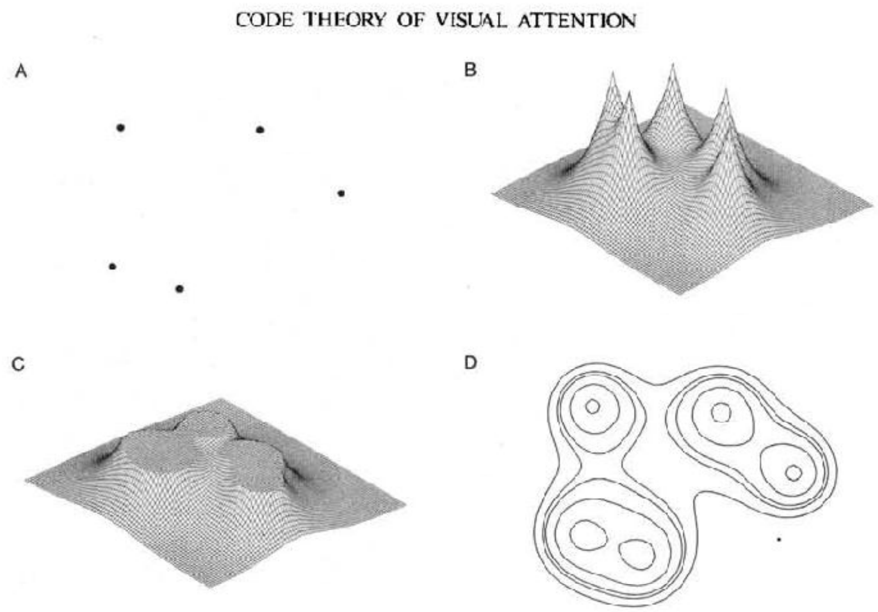

Fig. 1.2. A dot pattern arrayed in two dimensions (A), the corresponding CODE surface (B) with a threshold applied to it (C), and a contour map of the CODE surface (D) representing all possible groupings of the dots in the pattern (taken from Logan, 1996).

Itti & Koch (2000): The Saliency Map Hypothesis

While Findlay & Walker's (1999) model is well specified it is not implemented; and while the CODE theory of visual attention is implemented it only predicts manual response data (accuracy and reaction times), not eye movements. Itti & Koch's (2000) saliency map model gives a more stringent account, providing simulated data to which the eye movements of human observers can be compared. The saliency map model is an algorithm which computes saliency peaks by extracting information at multiple spatial scales, and combining the information into a master saliency map. The master saliency map is derived from feature maps which highlight discontinuities in intensity, colour and orientation; therefore regions which stand out most from their background are identified in a quantifiable way. Based on these aggregated image statistics sequences of fixations are predicted which select regions in order of descending saliency. The model relies on inhibition of return to account for the serial order in which fixations proceed: once a location has been inspected it is transiently inhibited to prevent it from re-capturing attention (Tipper et al., 1994).

This model of attention is a very worthwhile step in vision research for three reasons. First, it is a testable model with set parameters against which actual eye movement recordings can be compared. Second, it details how different visual properties which are not directly comparable can be equated in terms of salience. Third, realistic natural photographed images can be run through the model, a fact which is particularly advantageous given the reliance on basic low level target detection paradigms in Findlay & Walker's (1999) model. The master saliency map in Itti & Koch's (2000) model may be thought of as a fully elucidated version of the saliency map contained in Findlay & Walker's WHERE pathway.

Like Findlay & Walker's (1999) model, the saliency map model is largely centred around stimulus driven eye movements, leaving the contribution of top-down factors to eye guidance to be outlined by others : "Top-down cues in humans might indeed bias the attentional shifts, according to the progressively constructed mental representation of the entire scene, in inappropriate ways. Our model lacks any high-level knowledge of the world and operates in a purely bottom-up manner" (Itti & Koch, 2000, p. 1502; though see Navalpakkam & Itti, 2005, where simple top-down attentional allocation is modelled by weighting the saliency channels).

With 'bottom-heavy' modelling the differences between a system which lacks high-level knowledge of the world and one which does not are evident. Employing Itti & Koch's (2000) model several studies have shown that low level visual saliency is less important in the perception of natural scenes than top-down factors such as 'gist' or semantics, and that eye movements are easily guided towards predefined target objects early in viewing thus overriding the influence of saliency (e.g. Foulsham & Underwood, 2007; Underwood & Foulsham, 2006; Underwood, Foulsham, van Loon, Humphreys, & Bloyce, 2006). Such findings do not entirely negate the saliency map hypothesis, but illustrate the dynamic interplay between low and high level processes in the human visual system.

There have been several adaptations to the saliency map model therefore, which attempt to account for this interplay by incorporating top-down control. Variations on the concept of a 'target template' to which items in the visual array can be compared are popular (e.g. Rao, Zelinsky, Hayhoe, & Ballard, 2002). A target template allows eye movements to be driven by the internal goal to locate a particular item, matching bottom-up saliency with the stored representation. Saliency has also been integrated with contextual guidance in scenes, the initial bottom-up saliency map being passed through a global filter which specifies the likelihood that particular spatial locations will contain the target given the context (Torralba, Oliva, Castelhano, & Henderson, 2006). If searching for pedestrians in a city scene for example, one would not search rooftops, even if this is where the most salient locations are found; rather, search would be limited to streets and roadways. Torralba et al. (2006) allow saliency to be refined with the introduction of these *spatial priors*, or areas of maximal target detection. Visual saliency still guides eye movements within these context dependent areas, but top-down knowledge about the 'gist' of the scene can dominate, honing in on extended spatial locations depending on the task in hand.

Despite the modifications to Itti & Koch's (2000) original formulation of saliency and eye movements, for the purposes of this thesis the saliency map model (or variations thereof) was not chosen as the basis on which to ground eye movement training. This is because the training strategies reported in this thesis are intended to utilise top-down control, and Itti & Koch's (2000) algorithm is purposefully and predominantly designed around bottom-up input. Even considering alternatives to the saliency map model which take cognitive influences into account, one is left with commendable explanations of why people look where they do, but less in the way of methods to improve visual search performance via training. However, some notable possibilities are considered below.

The known differences between novices' and experts' visual scanning strategies (Crundall & Underwood, 1998; Martell & Vickers, 2004; Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996; A. M. Williams, Davids, Burwitz, & Williams, 1994) could be exploited by Itti & Koch's (2000) algorithm to advance our understanding of eye movement training protocols. For instance, weighting the feature dimensions more readily fixated by experts (cf. target template search, Rao et al., 2002), or restricting the influence of saliency to within spatial locations where experts prefer to look (cf. spatial priors, Torralba et al., 2006), would bias the model to more accurately recapitulate the scan paths of experts. This may go some way towards simulating expertise for situations in which humans could be replaced with an artificially intelligent interface. However, the goal of this thesis is to improve our understanding of eye movement training in human observers, not to improve the computational modelling of visual attention. Moreover, there is reason to believe that applying the above principle to the development of visual training regimes for novices would not work. Previous research suggests that simply having novices adopt the visual scanning behaviour of experts does not necessarily lead to performance gains, perhaps because the novice does not have sufficient automated skill to utilise the eye movement strategies of their more experienced counterparts (Chapman, Underwood, & Roberts, 2002; Donovan, Manning, Phillips, Highman, & Crawford, 2005).

There are other possibilities to manipulate the saliency map model for the development of visual training protocols, but the main reason Findlay & Walker's (1999) framework was chosen in preference was because although Itti & Koch's (2000) model and variations thereof deal with one aspect of visual search very thoroughly (location selection), they entirely omit any explanation of fixation durations. This is crucial to an understanding of visual search and eye movement training because fixation duration is known to be a good index of processing difficulty and information acquisition (Morrison, 1984; Reichle, Pollatsek, Fisher, & Rayner, 1998). If visual search is to be improved via training this means improving not only the ability to shift gaze to appropriate locations, but also the ability to effectively withdraw information when fixating. Findlay & Walker's concise description of the 'push-pull' relationship between saccades and fixations, plus the scope for further advancement of the higher levels on top-down control, are pertinent reasons the present thesis is based on this framework.

Reading

Another vast research area which pertains to eye movement control is reading. This area is of particular concern for the current thesis because of its focus upon fixation durations and information processing within a fixation, components of visual search that may be trainable via Findlay & Walker's (1999) WHEN pathway. Two of the most well known models of eye movements in reading are covered in this section: E-Z Reader (Rayner, Li, & Pollatsek, 2007; Rayner, Pollatsek, Drieghe, Slattery, & Reichle, 2007; Reichle et al., 1998; Reichle, Rayner, & Pollatsek, 2003), and SWIFT (Saccade generation With Inhibition by Foveal Targets, Engbert, Longtin, & Kliegl, 2002; Engbert, Nuthmann, Richter, & Kliegl, 2005).

Keith Rayner and colleagues have been at the forefront of reading research for many years, and their 'E-Z reader' model of eye movements in reading is well acknowledged. E-Z reader rests on several fundamental tenets: (i) that lexical processing when reading proceeds sequentially, beginning with an initial "familiarity check" before a second stage of lexical completion, whereupon the word is recognised and fully processed; (ii) that attention is decoupled from saccade programming, such that the programming of a saccade follows the initial familiarity check, whereas attention does not move to the next word until after the second stage of lexical completion; (iii) that the timing of saccades is determined by lexical processing –"word identification being the engine driving the eyes forward" (Reichle et al., 2003, p.463); (iv) that attention moves in a strictly serial manner from one word to the next.

E-Z reader is a fully implemented computational model and simulates some well known experimental effects, such as the detrimental effect of foveal difficulty on parafoveal processing. This is known as the 'preview benefit' (Henderson & Ferreira, 1990) and indicates that there is a temporal delay in the allocation of attention to the next word $_{(n+1)}$ when the currently fixated word $_{(n)}$ is difficult to process, perhaps due to being uncommon (low frequency) or of high syntactic complexity. This effect is manifest in longer (often first) fixation durations on word$_{n+1}$ as the processing difficulty of word$_n$ increases. E-Z reader accounts for this finding with the assumption that the saccade program to word$_{n+1}$ begins immediately after the initial familiarity check on word$_n$; however, because attention does not move to word$_{n+1}$ until after the second stage of lexical completion on word$_n$, attention affords less parafoveal preview benefit for the apprehension of word$_{n+1}$ when it is impeded by devoting resources to word$_n$ for longer.

While this explanation is succinct it is problematic because it is inconsistent with observations from the attention literature. Namely, pre-motor theory (see Rizzolatti, Riggio, & Sheliga, 1994) identifies attention as being synonymous with saccade programming –an attention shift is simply the motor program to initiate a saccade. This principle also underpins Findlay & Walker's (1999) model which intentionally removes the necessity for attention. While one may accept, due to contentions in the literature, that attention can be decoupled from eye movements as E-Z reader purports, the idea that a saccade program can *precede* an attention shift is rather counterintuitive and more difficult to reconcile.

Moreover, in the E-Z reader model saccade timing and saccade target selection are regarded as inseparable; however, as we have seen in Findlay & Walker's (1999) model, evidence from neurophysiology and from eye movement recordings is in contrast to this view, suggesting that 'when' (i.e. timing) and 'where' (i.e. targeting) are distinct both anatomically and behaviourally.

The nuances of eye movements in reading are intricate, and discussion of them is limited because reading is not the topic of this thesis. However, I will mention one more much debated observation because it is one of the principal findings which motivated SWIFT (Engbert et al., 2002; Engbert et al., 2005), the second model of eye movements in reading to be covered.

Several researchers have presented evidence which suggests that the opposite of parafoveal preview benefit can sometimes occur. It appears that characteristics of word$_{n+1}$ such as word length (Kennedy, 1998), frequency of the beginning letter sequence (Underwood, 2000) , and semantics (Inhoff, Radach, Starr, & Greenberg, 2000) can influence the processing of word$_{n.}$ These findings present a problem for models of eye movements in reading which argue that attention is serially allocated from one word to the next, such as E-Z reader.

The apparent bidirectionality of attentional effects from adjacent words, along with other controversial issues with E-Z reader, has lead some researchers to propose models in which eye movements are guided by an attentional gradient when reading sentences. SWIFT is perhaps the best known of these models, and the features which set it apart from E-Z reader are summarised below.

Within SWIFT's architecture attention is spread over an asymmetrical area extending approximately one word to the left of fixation and two words to the right (in accordance with what is known about 'perceptual span' in reading [see, for example, Henderson & Ferreira, 1990]). While E-Z reader also allows for perceptual span (i.e. the extended area around fixation within which preview benefit is possible), the distinction in SWIFT is that lexical processing is *distributed* within this attentional window, with word identification being optimal at the fovea and decreasing as a function of eccentricity. Note that this conception of attention is in stark contrast to E-Z reader in which the 'spotlight' of attention progresses forwards strictly serially from one word to the next (see Fig. 1.3). Herein lies another notable feature of SWIFT which differentiates it from E-Z reader: SWIFT incorporates an autonomous saccadic timer which mediates eye movements so as to maintain a preferred mean rate of saccades. When lexical access is delayed by words which are difficult to apprehend, a mechanism for inhibition by foveated words keeps the default temporal interval between eye movements in check; this ensures that eye movements and lexical processing do not desynchronise. Hence, lexical processing does not drive the eyes forward in SWIFT as it does in E-Z reader; moreover, the inclusion of a separate parameter for saccadic timing is in better agreement with the evidence cited by Findlay & Walker (1999) pointing to a distinction between the WHERE and WHEN pathways.

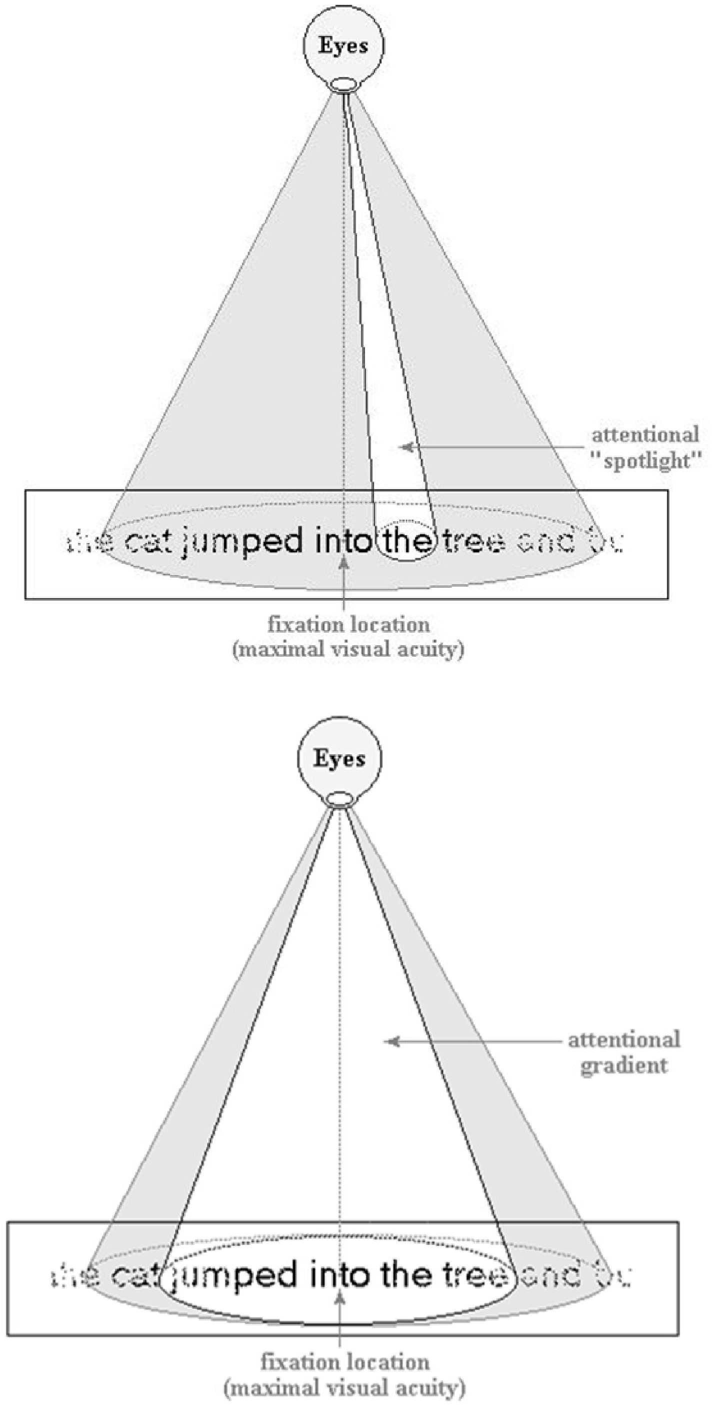

Fig. 1.3. The difference between how attention is conceived in E-Z Reader (top) and SWIFT (bottom). The former suggests attention operates like a spotlight moving serially from one word to the next, while the latter argues for a graduated attentional window (adapted from Reichle et al., 2003).

SWIFT is the main competitor to E-Z reader, and with 'distributed lexical processing' it is able to account for 'parafoveal-on-foveal' effects. However, I do not wish to give the impression that SWIFT is a more comprehensive model than E-Z reader. It is an alternative. And Rayner et al. (2007) convincingly defend their model, explaining why 'parafoveal-on-foveal' effects do not necessarily negate the premises of E-Z reader. They argue that such findings are not widespread, and when they do occur they reflect small but inherent errors both in the accuracy of eye tracking devices and the precision of the oculomotor targeting system.

Some of the modelling principles in reading have been applied to visual search performance and scene perception. Henderson (1992) proposes the 'Sequential Attention Model' which is similar to E-Z reader in that, as the name suggests, attention progresses serially from one item to the next with foveal processing preceding saccade programming. Henderson's model also shares some commonalities with SWIFT because it imposes a temporal deadline on saccade programming which restricts the duration of fixations to a maximum value the visual system will tolerate. If processing is completed close to this deadline preview benefit is reduced because attention will not have progressed to the next location; if processing is not completed within this deadline a re-fixation ensues. Henderson observes favourable correspondences between his model and eye movement recordings, both in reading and picture viewing; however, others have found the fit to be imperfect in visual search tasks. For example, van Diepen & d'Ydewalle (2003) report that when peripheral information is masked early in a fixation, saccade target selection is affected; this should not happen if foveal processing is completed in sequence before saccade programming. Moreover, van Diepen & d'Ydewalle also found that foveal masking does not lead to an extension in fixation durations comparable to the mask duration, which would be expected if the sequential attention model is correct and foveal processing is delayed until the mask is removed. While the former point concerning early peripheral masking may be accounted for by the sequential attention model with reference to the fact “early” is a relative term, and therefore the mask may not have been “early” with respect to short fixations, the latter point is more difficult to reconcile because it suggests that in the absence of useful information at fixation peripheral processing can occur first (van Diepen & d'Ydewalle, 2003).

The fact that task constraints, current goals, and prior experience effect eye movement control, and that these elements are subject to large degrees of variability, makes eye movements extremely difficult to synthesise in computational models. Equally however, this evident malleability of the visual system reflects that it may be adaptable through training. This is the area of research I will turn to next.

1.3. Visual Training

Perceptual Learning

One way visual training can be conceptualised is with reference to the literature on perceptual learning. This research area is vast, and is covered only in enough detail to give a flavour of how it relates to the topic of this thesis: training eye movements.

One of the leading theoretical accounts of perceptual learning is Ahissar & Hochstein’s (2004) Reverse Hierarchy Theory. Within this theory learning is mediated by task difficulty which in turn determines the neural site of learning, and therefore the extent of transfer to new situations. This is a *reverse* hierarchy because generalised top-down resources initially guide vision, with more specialised lower level resources being recruited when high level representations are inadequate (for example, with finer grained discriminations judgements). When trained with tasks requiring neuronal populations which reside in higher cortical areas, the resultant learning generalises to tasks which recruit lower cortical areas. With increasing task difficulty however, learning becomes restricted to the lower cortical areas which sub-serve the greater selectivity necessary to meet the increase in task demands.

Thus, Ahissar & Hotchstein's experimental procedures typically involve the brief (<250ms) presentation of an array of obliquely oriented lines, amongst which a single target line, differing in orientation from the homogeneous distractors, must be found (Ahissar & Hochstein, 1996, 1997, 2000; Ahissar, Laiwand, Kozminsky, & Hochstein, 1998). This task would be easy from the outset, giving rise to 'pop-out' search (cf. Treisman & Gormican, 1988), were it not for the short presentation window, and the addition of a mask of asterisks matched to all line orientations following variable onset asynchronies after the stimulus array. Within this paradigm task difficulty can be manipulated in several ways: adjusting the stimulus-to-mask onset asynchrony (SOA; short SOAs being harder), varying the difference in orientation between target and distractors (greater similarity being harder [cf. Duncan & Humphreys, 1989]), and using different target eccentricities (larger eccentricities being harder because central fixation is maintained throughout, and the parafovea has lower acuity than the fovea [see, for example, Bear, Connors, & Paradiso, 2001 pp. 293-295]). Learning can be assessed with this procedure by having participants complete an initial training phase in which one of the independent variables outlined above is manipulated, followed by a test phase where stimulus presentation is uniformly random. Upwards of 1000 trials are used for each phase allowing perceptual learning to be compared pre- and post- training.

A reliable pattern emerges: with increasing difficulty level learning is slower and generalises less beyond the training parameters; but importantly, the spread of learning encompasses target locations and orientations that were never trained. This concurs with what is known about the hierarchy from retina to cortex, via the dorsal and ventral visual streams. For example, since the pioneering work of Hubel & Wiesel (1962) we have known of simple, complex, and hyper-complex cells, which respectively encode more difficult information higher up the visual pathways. Simple cells are responsive to specific orientations when presented *in a set location* of their receptive field; complex cells are responsive to specific orientations presented *anywhere* in their receptive field; and hyper-complex cells can encode the end-points of individual line orientations presented within their receptive field. Ahissar & Hochstein's paradigm reveals that when the task is difficult (e.g. short SOA's) learning is orientation specific and also position specific –like the coding of simple cells; however when the task is easier (e.g. longer SOA's) learning transfers to new locations –like the coding of complex cells. And thus task difficulty determines the specificity of learning as we move further and further up the visual hierarchy. The generalised training benefit for easier tasks is independent of the training parameters *providing that perception of post-training stimulus attributes is sub-served by lower cortical levels in the visual hierarchy than those at which the training benefit is manifest.*

The reverse hierarchy account provides a sound basis for understanding other avenues of research in perceptual learning. The interfering effect of concurrent stimuli in dual tasks demonstrates the capacity limits of visual attention, and examples are numerous in the literature (see Pashler, 1999, for a review). Chirimuuta, Burr, & Morrone (2007) elegantly demonstrate that a secondary task has a detrimental effect if it requires resources from the same modality as the primary task. For example, search for an 'odd' coloured target among identically coloured distractors negatively affects colour contrast thresholds when both tasks are presented at the same time; conversely, when the colour search task is presented on a background assessing *luminance* discrimination thresholds, there is no evidence of such interference. Importantly however, this modality specific effect can be abolished with over-training, and the authors suggest V4 is the site of this plasticity. In terms of the reverse hierarchy theory this would presumably implicate all visual areas along the pathway from retina to cortex up to V4, and not beyond. Indeed Chirimuuta et al. report transference of learning to new (i.e. untrained) target positions, which is consistent with the reverse hierarchy account.

However, are some attentional demands simply too difficult to benefit from training? Some research suggests this is the case. Like Chirimuuta et al. (2007) Braun (1998) reports that a pop-out search task is hindered by a concurrent central attentional blink task (this is the momentary temporal lapse in attention following the detection of a pre-defined target in a rapid serial visual presentation [see, Raymond, Shapiro, & Arnell, 1992]), and that this effect can be attenuated with extended training. However, when the 'pop-out' task is replaced with the more demanding T/L discrimination of one item in the periphery, no amount of exposure training seems sufficient to ameliorate the interference from the attentional blink task. Awareness of attentional capacity and capacity for improvement via training is important for the design of training regimes in the current thesis.

There are more tangible examples of how perceptual learning can affect performance in 'real-world' tasks. In line with the focus of this thesis these relate more specifically to eye movements, whereas the above examples are purely attentional, central fixation being maintained throughout. One such example is the eye movements of advanced chess players which reveal superior perceptual span (Reingold, Charness, Pomplun, & Stampe, 2001). This may be important for training eye movements with respect to the distinction between WHERE and WHEN in Findlay & Walker's (1999) model, because it suggests that with increasing expertise, fixations can be more efficient at extracting relevant information from the periphery without the need to move the eyes. The finding of an increase in the spatial region about fixation from which task-relevant information can be drawn is not limited to expert chess players. Indeed, we have already seen evidence about perceptual span in reading, and there is reason to believe that this span increases with perceptual learning even in arbitrary visual search tasks (Phillips & Edelman, 2008).

Others have deliberately trained eye movements with the purpose of improving fixation efficiency in video game play (Shapiro & Raymond, 1989), shedding light on the training parameters which give rise to the known performance gains associated with gaming (Green & Bavelier, 2006). It has been shown that in none-gamers, both tailored training schedules linked to a specific test game and mere unstructured practice with an action video game can improve the spatial distribution of visuospatial attention (Shapiro & Raymond and Green & Bavelier, respectively).

In Shapiro & Raymond (1989) a series of training drills were used with the game “Space Fortress” to reduce the occurrence of unnecessary eye movements and encourage reliance on peripheral vision. Drill 1 instructed participants to maintain fixation of the space-ship as it moved around in the space fortress game, and press the fire button when a stimulus appeared. The stimulus was either a small dot presented close by the ship (i.e. ~ 3’ visual angle) or a moving ‘mine’ (which was dangerous if crashed into) presented elsewhere on the screen. The mine was large enough to be detectable in peripheral vision, while the dot was small enough that foveation was necessary to notice it. Thus, constantly fixating the ship was the most efficient strategy to ensure good performance. Drill 2 was identical except that mines were indicated as ‘friend’ or ‘foe’ with different responses required for each; hence the optimal strategy was the same here but the task was slightly harder. Finally drill 3 was designed to promote fixation of the ship while learning ship control; in this drill, although participants could not control the direction of the ship's motion, they could orient it to 'shoot' in the direction of a threatening mine, which they were instructed to do while remaining fixated on the ship. The training drills were interleaved with actual game play on space fortress over several sessions, and the results confirm that the drills were effective in establishing oculomotor behaviour consistent with their intent, and that this change in eye movements was coupled with a large improvement in game score. These results provide insight into the strategies that may be adopted by experienced gamers, and suggest ways learning could be accelerated by eye movement training in other tasks.

The work on perceptual learning in video game play therefore, nicely leads on to the next section to be covered on visual training; that is, how eye movement training can be used as a tool to improve skills in applied areas.

Training eye movements in applied domains

Eye movement training has many applications and has been studied in a variety of areas including developmental learning disorders such as dyslexia, clinical disorders of the eye such as macular degeneration, medical practices such as radiology, driving, and a range of different sports. I will cover some of this research in this section, before going on to explain how the approach adopted in the present thesis adds value to the existing research base.

Some research suggests a deficit in voluntary saccade control in children with developmental dyslexia which may contribute to their problems reading and, indirectly, spelling. Revealed with anti-saccade tasks in which reflexive saccades must be suppressed and saccades generated in the opposite direction to abrupt onset stimuli, this evidence shows that dyslexics can have problems inhibiting stimulus elicited saccades (Fischer & Hartnegg, 2000). However, these problems can be averted with daily practice. Fischer & Hartnegg used three training protocols and successfully improved voluntary saccade control in dyslexic children. The first protocol required participants to fixate a centrally located rotating T shape, and report its final orientation before offsetting (because the offset occurred at a random interval the optimal strategy was to foveate it throughout). The second training procedure was the same as the first except the T symbol jumped unpredictably to the left or right of the screen before offsetting, therefore requiring a saccade to detect its final orientation. In the third training task a stimulus was first presented centrally before jumping to the left or right of the screen; when it did so the rotating T shape was presented on the opposite side of the screen and the trainee had to report its final orientation as before.

With progressive training over 3-8 weeks in which the orientation change of the T shape was speeded up as the participants improved (making the task harder) dyslexics' oculomotor behaviour reached normal asymptotes, and they were able to inhibit exogenous saccades and execute voluntary saccades in anti-saccade tasks. However despite this, only slight improvements in reading skill were observed post-training, suggesting that while the ability to self-regulate eye movements may be necessary for fluent reading, it is not sufficient, and that we still have much to learn about the conditions in which training can enhance reading performance in developmental dyslexia.

Training which involves no direct practice with reading but instead focuses on eye movement control has led to improvements in reading in other areas however. Macular degeneration is a disorder of central vision in which the fovea becomes diseased leading to a decline in acuity at fixation and a reliance on parafoveal vision. This disorder leads to associated sensory and oculomotor impairments; therefore it inevitably hinders normal reading. Seiple, Szlyk, McMahon, Pulido, & Fishman (2005) used a range of training schedules in patients with macular degeneration over an eight week period and measured the training effects and their transference to reading. The procedures involved: (i) training saccade control with dots or letters alternating between two locations; (ii) matching tasks in which letter pairs were alternately presented either centrally or peripherally in a block, and the patient had to report whether the pairs were the same or different; (iii) word identification, both with serial presentation at fixation and with words alternating between peripheral locations; (iv) predictable or unpredictable search respectively, in which letters were either presented in a clockwise sequence around the screen or appeared at random; (v) and, a moving window technique in which a sequence of words or letters were presented from left to right, and the preceding item in the sequence disappeared on each redraw.

Daily practice with these training exercises, as well as leading to improvements on the tasks themselves, also gave rise to gains in visual acuity and an overall significant improvement in reading speed. A likely reason that this study was successful in elevating reading performance while the aforementioned study on dyslexia was not is that macular degeneration is predominantly a disorder of the eye, whereas dyslexia is more related to higher cognitive functions. It may be therefore that training the “software” of the visual system is more of a challenge than training its “hardware” (A. M. Williams & Grant, 1999, discuss this distinction). Such a distinction with the transference of training has close parallels with the reverse hierarchy account (e.g. Ahissar & Hochstein, 2004).

Related results suggest that training benefits with purely optical visual disorders may be generalised and persistent. Liu, Kuyk, & Fuhr (2007) report that practice finding a 2° square amid 1° squares at various set sizes and display eccentricities, leads to steady improvements in accuracy and reaction time over a 5 day training period in patients with a range of eye disorders from age-related macular degeneration, to glaucoma, and diabetic retinopathy. Moreover, the positive influence of training in these tasks remains when reassessed at one month follow-up.

There has also been some success in training the eye movements of novice drivers. With the use of a hazard perception training package called RAPT (Risk Awareness and Perception Training), which demonstrates where attention should be allocated to efficiently detect risk in hazardous scenarios, Pradhan, Fisher, & Pollatsek (2006) showed that the eye movements of novice drivers can be made to resemble their more experienced counterparts. This was assessed with a driving simulator where driving situations containing information crucial to safe navigation unfolded as participants maintained control of the simulated vehicle. The eye movement record following training revealed that participants were twice as likely to pre-empt risk by fixating potentially dangerous regions in anticipation of a hazard. It is also encouraging to note that these effects are reasonably long-lasting because when re-assessed on the simulator at 4 days follow-up the magnitude of the training effects are not significantly different from those observed immediately after training. However, a note of caution is necessary here because one cannot be sure that the effects of training extend beyond the computer generated roadways in which they were assessed. For example, although Chapman et al (2002) report comparable improvements on real roadways in novices trained with similar methods, they also point out that the changes in visual scanning behaviour observed do not extend to more demanding driving situations such as dual carriage ways. The authors attribute this to insufficient automated skill in vehicle control: as the primary task of driving becomes more challenging, with the consequences of a crash being higher stake, the training strategies may be abandoned.

The results on training eye movements in sport are more mixed than those from the literature on driving. It is apparent that expertise in sports, like experience in driving, is reflected in visual scanning behaviour; with advanced players and drivers alike presenting with oculomotor statistics that differentiate them from novices (Crundall & Underwood, 1998; Martell & Vickers, 2004; A. M. Williams et al., 1994). Some researchers have exploited these differences and trained eye movements to emulate those characteristic of athletes. One such example is 'Quiet Eye' training (Harle & Vickers, 2001), where the longer final fixation durations of elite basketball players prior to a free throw are encouraged in trainees by structured training exercises. This technique does improve the basketball free throw in experimental testing sessions, though it is more difficult to conclude that Quiet Eye training transfers to actual games (despite the marginal increase in free throw shooting accuracy over the basketball season) because eye trackers are prohibited from competitive play.

Several lines of enquiry suggest that the advantages of visual training in sport observed under laboratory conditions *do not* transfer to actual game play in the field (Quevedo, Sole, Palmi, Planas, & Soana, 1999; and see A. M. Williams & Grant, 1999, for a review). Systematic evaluation of the visual training exercises endorsed by authors in publically available sources (e.g. Arie, 2008; Revien & Gabor, 1981) reveals that these "eye exercises" simply do not work, and that the training benefits reported are due to nothing more than test familiarity (Abernethy & Wood, 2001). Meticulously following the procedures suggested in Dr. Revien's Eye Exercises for Athletes (1981), Abernethy & Wood (2001) had participants use a wide range of visual training tasks outlined by Revien. These included, but were not limited to the following:

1. *Chord ball training* – here, a 3 meter long taut length of chord is stretched out from between the eyes. Beads are located at different distances along the chord, and the participant is required to make rapid fixational shifts between the beads with the aim of enhancing accommodation (focussing on single objects using the lens of the eye) and vergence (focussing on single objects with orbital changes of the eyeball).
2. *The swinging ball exercise* – here, participants are required to track a swinging ball with the aim of promoting smooth coordinated eye movements and reducing distraction.
3. *Colour rotator exercise* – here, a disk containing a single black dot amid shapes and sizes of different colours is rotated, and the participant has to track the black dot. The aim is that peripheral awareness will be improved by the stimulation from bright background.
4. *Flip card practice* – here, a deck of cards each containing a central fixation dot flanked by two numbers is used. The numbers are equidistant from the dot but their eccentricity increases from the beginning to the end of the deck. The participant rapidly flicks through the deck and has to identify both numbers on each card while maintaining central fixation. The aim is to increase perceptual span and speed of recognition.

Compared to controls, the visual training group who practiced with the procedures listed above showed no greater pre- to post- test improvements, either in visual function or sports specific motor performance. The authors attribute this to that fact that Revien's (1981) training tasks focus on basic visual functions, while these are not typically factors that limit high level sports performance. While there are differences in eye movement statistics between experts and novices, as noted above, these differences are in the utilisation of appropriate information not low level visual function.

In summary of the ventures to train eye movements in applied domains covered in this section, it seems that while eye movements can be altered through visual training, these changes are not always beneficial. The clearest cases of training producing the desired outcomes come from clinical populations presenting with underlying physiological problems with the visual system to begin with (such as age-related macular degeneration etc.). The basic functional and mechanical aspects of the eye may be adaptable through perceptual learning and eye movement training, but there is ample room for expansion on how to integrate this with higher cognitive functions to bring about genuine training benefits in tasks which rely on top-down factors.

1.4. Thesis Outline

As we have seen in the literature review above, although efforts are being made to advance current models of visual attention and eye movements by incorporating top-down control into their architecture, there remains much we do not fully understand about the influence of higher level cognitive factors on eye movements. Moreover, there is an apparent gap in the available evidence on training eye movements: attempts to train eye movements to improve human skill in everyday activities are often made without reference to existing theoretical and computational models. However, existing models of eye movements are often underspecified in the very area on which real world tasks depend: top-down influences. Therefore, the development of eye movement training strategies which utilise top down control based on existing models would have two-fold advantages. First, it would ensure that eye movement training for complex tasks has a strong theoretical grounding, as opposed to being based on anecdotal evidence as some have suggested (e.g. A. M. Williams & Grant, 1999, p.197). Second, it would add to the progress being made in integrating top-down into predominantly bottom-up models of visual attention and eye movements.

To this end Findlay & Walker's (1999) model was chosen over others as the basis on which to develop eye movement training strategies because, unlike any of the other models reviewed in section 1.2, it is a general purpose model which accounts for many eye movement phenomena with explicit reference to *both* behavioural properties of eye movements: saccade targeting *and* fixation duration. Moreover, it concisely describes the functional coupling between these two components by way of the reciprocal inhibitory relationship between the WHERE and WHEN pathways respectively. Lastly, as I pointed out when reviewing Findlay & Walker's model, there is scope for its improvement by harnessing top down control in levels 4 and 5.

However, it is necessary at this juncture to qualify what I mean by top down control in relation to eye movement training. Often in the visual training literature learning is achieved through many hundreds of trials until the effects of practice become automated. In this sense top-down is the relatively automatic deployment of enhanced perceptual resources and visuomotor skill. However, can this route be bypassed with strategic advice about how to move the eyes, perhaps implicating the higher level and voluntary aspects of eye movement control tentatively outlined in levels 4 and 5 of Findlay & Walker's model respectively?

The experiments I go on to present in subsequent chapters suggest the answer to the above question is yes, and that eye movement training strategies can improve performance without time consuming perceptual or visuomotor learning. Typically, the training documented in this thesis involved informing participants of contingencies to which abstract stimuli adhered, thereby allowing them to carry out the two components of my experimental tasks more efficiently: visual search, and stimulus discrimination. I will show that these elements of visual behaviour can be separable, and that top down training directed towards the WHERE and WHEN pathways can be related to each respectively. The effects of directing training in the manner described can be beneficial and additive (Chapters II and III), highlighting that previous attempts to train eye movements could be more effective if they concentrated upon stimulus processing *as well as* assisting in the ability to visually locate relevant stimuli.

However, I will also demonstrate that the improvements in visual search time attainable by training the WHERE pathway in isolation can obscure hidden detriments associated with processing foveated items (Chapter IV). This exemplifies the push-pull relationship between the WHERE and WHEN pathways, suggesting that that attempts to train eye movements which focus on rapid and vigilant visual scanning (e.g. Coyne, 1997) may increase activation in the Move centre (regulated by the WHERE pathway) and decrease activation in the Fixate centre (regulated by the WHEN pathway). Consequently the information acquired from each fixation may be incomplete, increasing the likelihood of relevant items being missed during viewing even if they are fixated. Chapter IV evaluates the circumstances in which this effect is likely to occur, and highlights how it can be abolished by recruiting resources sub-served by the WHEN pathway. It therefore has the dual benefit of assessing whether we should be concerned about current advice on eye movement training, while identifying how potential concerns may subverted.

The findings in Chapters IV have implications for training eye movements in drivers; particularly given the suggestion that encouraging eye *movements* may actually reduce the probability of noticing important information. Therefore, Chapter V explores eye movement training in relation to hazard perception in drivers, grounding the results reported using abstract visual arrays in an applied area (this was also a requirement of the ESRC competition studentship which funds this work).

All the data presented is discussed throughout, but any outstanding issues are addressed in the General Discussion (Chapter VI). Here I attempt to integrate my results into Findlay & Walker's (1999) framework, and I suggest additions and modifications to the model where appropriate. With this evaluation I outline worthwhile avenues for further research in this final chapter.

2. Chapter II – Move & Fixate training, independently and in concert

The first aim of this thesis was to establish whether eye movement training could be related to Findlay & Walker's (1999) hypothesised Move centre (in which activity in the WHERE pathway culminates) and Fixate centre (in which activity in the WHEN pathway culminates). I wished to address whether training which advised people where they should move their eyes, could be separated from training which reduced the information processing demands encountered when fixating stimuli difficult to apprehend. The former point would relate to the Move centre, while the latter would relate to the Fixate centre.

Stimuli were therefore developed in which the attributes defining a target differed from the attributes defining the required response –thus allowing visual search for a target to be separated from subsequent target processing. For instance, a target could be defined by a conjunction of features –red *and* square –but the correct response to the target, once identified, could require reference to the *number* of red squares of which it consists (see Fig. 2.1, below).

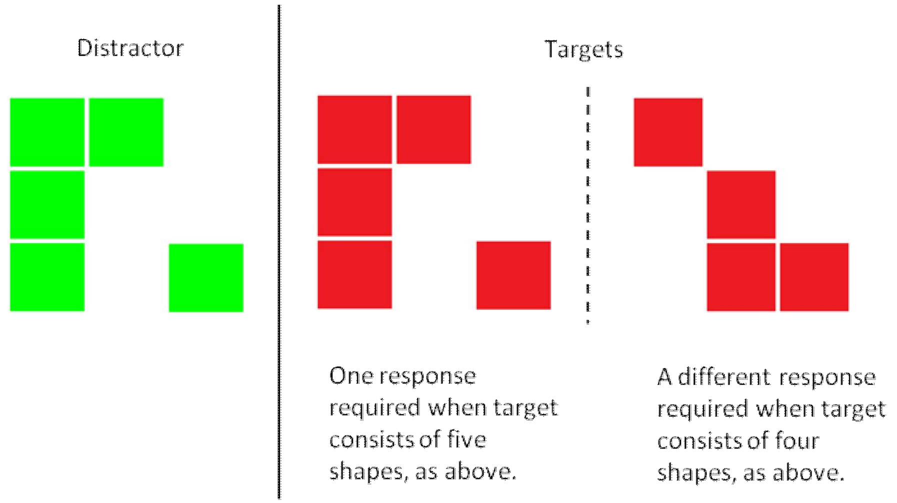

Fig. 2.1. Example stimuli used in this chapter. Targets and distractors consisted of a collection of homogeneous shapes. Here targets are red squares. The correct target response differs however according to how many shapes the target is comprised of.

Different targets and distractors, as illustrated above, can be used for visual search. In Fig. 2.2 below, the same target stimulus as the middle panel of the above figure (Fig. 2.1) is located in the top left corner. Individual targets and distractors will henceforth be referred to as sub-array stimuli, located within an overall search array. Searching the 3x3 search-array for the 3x3 sub-array target requires eye movements; it is a spatial localisation task necessitating global scanning of the display. However, once the target is identified, its local features *within* the sub-array must be scrutinised in order to discern the correct response according to the number of shapes that comprise the target. The initial requirement to find the target cannot be completed with reference to the subsequent conditions of responding to it and vice versa, therefore the two components of the task are distinct. This is important because it allows training to be directed to each aspect of the task independently: First visual search, predominantly mediated by the Move centre, and second stimulus discrimination, predominantly mediated by the Fixate centre. I will explain how training was implemented with respect to these two components of the task next, beginning with Move Training (MT) before clarifying FixateTraining (FT).

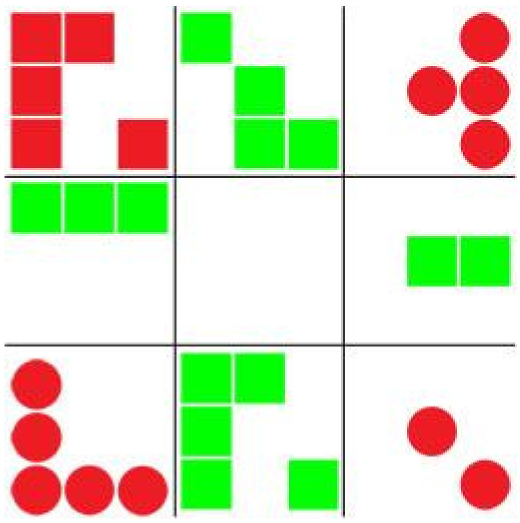

Fig. 2.2. An example target search array. Sectors of the 3x3 grid containing shapes will be referred to as the sub-array. One of the sub arrays will be a target stimulus, the remaining sub-arrays will be distractors. In this case the target stimulus consists of red squares, and is located in the leftmost column of the top row. Hence targets differed from distractors in one feature dimension, colour or form. The central grid sector was always blank.

Eye *movement* training can assist visual search for the target in the paradigm described by ensuring that the target occurs in a predictable location from one trial to the next, and informing participants of this sequence. Fig. 2.2, above, represents a single trial display with the target in the top left sector of the search-array grid; in subsequent trials however, rather than being randomly determined, the target would appear in pre-set locations, one iteration a sequence specifying four target locations which continuously cycle (for example see Fig. 2.3, below).

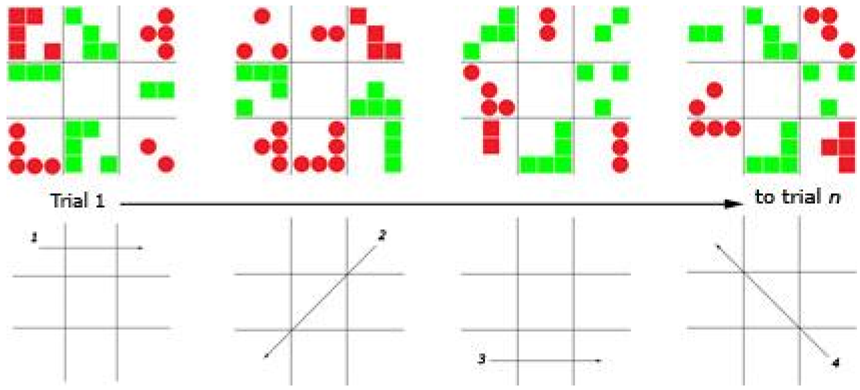

Fig. 2.3. An example sequence of four trials is shown in the upper panel. Targets (in this case sub-arrays containing red squares) are presented in a predictable sequence: top left, top right, bottom left, bottom right. Italicised numbers in the lower panel indicate the position of the target in the example trial directly above, the arrows show where the target will occur in the proceeding trial.

Participants directed with MT were informed of the predictable sequence of target presentation (e.g. Fig. 2.3), and told to move their eyes in the pattern to find the target more efficiently. Training eye movements in this way differs from much of the work on visual training described in the general introduction (Chapter I) because it does not involve learning via extensive practice over time; rather training is the deployment of a strategy to guide eye movements. This approach is purposefully chosen to establish the effects of top down control linked to the upper channels of Findlay & Walker's (1999) WHERE pathway, as opposed to exploiting the plasticity of bottom-up resources on which much of the visual training literature rests.

The same approach was also taken with training aimed at improving information processing at fixation. FT was implemented by informing participants of a contingency related to the response aspect of the task. It is likely that the reader has not noticed that the separation of responses according to whether the target is comprised of four or five shapes follows particular sub-array configurations: when a target consists of four shapes one of those shapes will *always* occupy the central region of the target sub-array; conversely, this central region will *never* contain a shape when the target consists of five shapes (see Fig. 2.4). In fact one can observe that this contingency is true for all target and distractor sub-arrays according to whether they are comprised of an odd or an even number of shapes. Thus, if a sub-array stimulus is made up of two or four shapes one of those shapes will always occupy its centre, and if a sub-array stimulus is made up of three or five shapes none of those shapes will occupy its centre. Once a target has been identified therefore awareness of this contingency will allow subsequent processing for the response discrimination to proceed more efficiently: one does not need to count the number of shapes of which the target is comprised, one can simply refer to the centre of the target and make the correct response for even or odd respectively according to the presence or absence of a shape in the central region of the sub-array. Like MT, FT is based on the use of a strategy, and similarly it bypasses the route to improvement through extensive practice over time. This is in line with previous observations that when a stimulus is unchanged, but its informational load is decreased, fixation durations decrease also (Gould, 1973; Zingale & Kowler, 1987), and Findlay & Walker (1999) argue that this provides evidence for top down mediation of the Fixate centre.

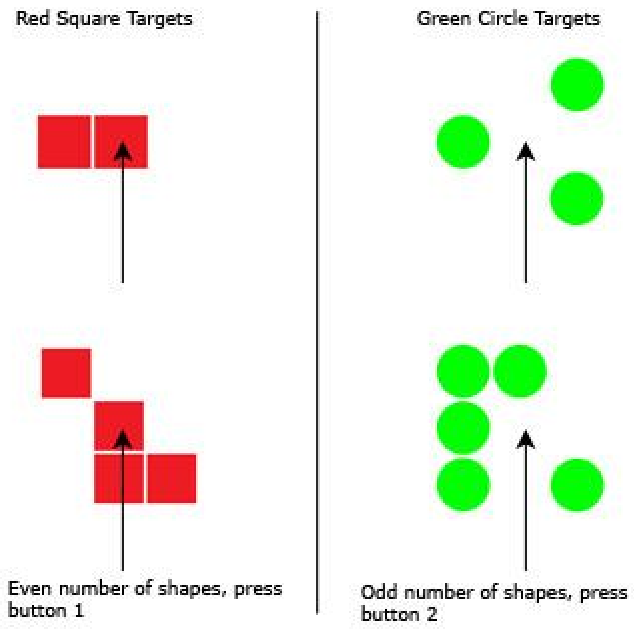

Fig. 2.4. All the sub-array stimuli shown above are potential red square and green circle targets. Without FT participants would have been required to respond to the target according to the number of shapes it contains: with one button press designated for even and another for odd. However FT informs participants that the first set of responses (for even; left panel) conforms to the rule that the centre of the sub-array stimulus will always contain a shape. Conversely, the second set of responses (for odd; right panel) conforms to the rule that the sub-array stimulus will never contain a shape at its centre. The arrows in the figure demonstrate this contingency, which held for button 1 and button 2 responses throughout the experiments described. Therefore, in the example above, instead of having to discriminate between the number of constituent shapes, FT simplifies target processing.

Two points become apparent at this juncture and require further qualification. First, it is revealed in Fig. 2.4 that targets could be one of two possibilities (red squares *or* green circles), a fact that has not been mentioned thus far. Because I sought to measure the effects of eye movement training in the visual search paradigm described it was necessary to ensure that finding the target was sufficiently difficult without such training. Either (but never both) of the target types shown in Fig. 2.4 could be presented in given trial, meaning that participants would have to search the 3x3 search-array looking for *either* red squares *or* green circles. Having two target possibilities guarantees that the object of search cannot be initially located via pre-attentive processes (Treisman & Gormican, 1988), guided search

(Wolfe, Cave, & Franzel, 1989), or inter-item similarity (Duncan & Humphreys, 1989). Even when a visual search target is defined on the basis of one conjunction of features (as shown in Fig. 2.2 & Fig. 2.3: red squares among red circles and green squares) it has been shown that search can search can still proceed efficiently if attention can filter out one of the irrelevant feature channels (Wolfe et al., 1989). De-weighting green in the colour channel for instance would limit search to squares amongst circles, of which only one group, the target stimulus, remains. The search can then proceed efficiently in parallel (i.e . serial self-terminating scan over all the items is not necessary). As participants completing the task described must hold two target templates in mind, each with features common to any potential distractor, it would not be possible to restrict the search in this way. Eliminating the possibility of participants locating the target by efficient parallel search was necessary to ensure a reliance on the training sequence of target presentation; if finding the target was too easy then there would be no need for participants to use MT.

The second, related, point concerns that fact that responses were separated according to whether an odd or even number of shapes constituted the target. Because two, three, four or five shapes were used in stimulus development, each of the two separate responses were attached to two criteria, and this reduces the likelihood that in the absence of FT participants will adopt their own strategies to rely on. For example if responses were only divided as in Fig. 2.1, where I only mention separation on the basis of targets containing of four or five shapes, one could develop the strategy that “if the stimulus is ‘cluttered’ it probably contains five shapes; therefore the default [when ‘uncluttered’] is four”. Dividing responses on the basis of odd or even in the manner described ensures that the response aspect of the task is sufficiently difficult, reducing the possibility that other strategies will be relied on, and increasing the probability that FT will benefit performance.

Finally, because these stimuli allow visual search and stimulus discrimination to be separated and Move and Fixate training to be directed at each respectively, they also permit conjoined training, with participants being informed of *both* the predicable sequence of target presentation *and* the contingencies relating to responding. It is with this progressive and additive influence of eye movement training in mind that experiments 1-4 are presented. Experiment 1 concentrates solely on FT; Experiment 2 MT; and Experiments 3 and 4 assess the additive influence of MT and FT in concert, highlighting that the benefits of FT are task dependent. Only manual response data was collected in this series of experiments (accuracy and reaction time). On the basis of the results obtained eye movement data was collected in a subsequent experiment using the same paradigm (Chapter III).

2.1. Experiment 1 - Fixate Training

The first experiment in this series sought to establish whether FT could be utilised with the stimuli described. Therefore only single stimuli (i.e. target or distractor sub-arrays) were presented, one at a time, removing visual search hence keeping training isolated to stimulus discrimination, which I have argued is related to the Fixate centre.

However, the task and stimuli I have described so far involve identifying targets on the basis of a conjunction of features, then responding to them on the basis of the number of shapes they contain. But are these two aspects of the task equally demanding? It is possible that the number discrimination judgment required will be easier than the identification of targets on the basis of their feature conjunction. We know from Logan's (1996) CODE theory of visual attention (outlined in Chapter I) that display items may be grouped by proximity and similarity as dictated by task demands. We also know from Treisman's (1988) Feature Integration

Theory that targets defined only by a conjunction of features are difficult to process and require selective attention. While this latter point has been questioned by others who argue that detection can still be efficient with feature conjunctions using the principle of guided search outlined above (Wolfe et al., 1989), I specifically aimed to rule out this possibility by incorporating two targets into the design. Hence it remains a distinct possibility that it will be easier for participants to subitize neighbouring shapes of the same colour, than it will be to discriminate between potential targets on the basis of their feature conjunction. To take account of this, and to assess how FT would relate to either of the stimulus attributes relevant to target identification and subsequent processing, the reverse of these dimensions was also used. This meant that in separate blocks of trials participants would either have to identify targets from distracters on the basis of their feature conjunction *or* on the basis of the number of shapes they contained. Likewise the response could be separated either on the basis of feature conjunction *or* number. All other factors governing the stimuli were kept orthogonal (i.e. there were still two types of target and two types of distractor, and two criteria were attached to each of two responses). FT was implemented in the same way as described (i.e. by informing participants to look to the centre of the stimulus to discern the correct response. See Fig. 2.4). It is predicted that training will lead to significant improvements in reaction time over No Training (NT), and may also improve accuracy. A subsidiary prediction moreover, based on the rationale outlined above, is that training will give rise to larger performance gains when it assists with responding according to feature conjunction.

2.1.1. Method

Participants

Thirty two paid participants (22 female) were recruited from the University of Nottingham's student population and surrounding local area (mean age 23yrs, range 18-36). All participants reported normal or corrected-to-normal vision.

Stimuli & Apparatus

Two hundred and fifty six stimuli, consisting of red or green, squares or circles, were used throughout the study (see Appendix 8.1 for full breakdown of stimuli used in this chapter). These stimuli were developed with Photoshop software and the shapes of which they were composed could appear in nine possible locations relating to the 3x3 sub-array (the sub-array grid was never visible but was used for purposes of size and position standardization, see Fig. 2.5). Square components of the stimuli were 26.9cm^2 while circles were 22.4cm^2 (see Fig. 2.1 for examples of individual stimuli). The dimensions given above represent on screen sizes when presented to participants on a 21″ FD Trinitron CRT monitor.

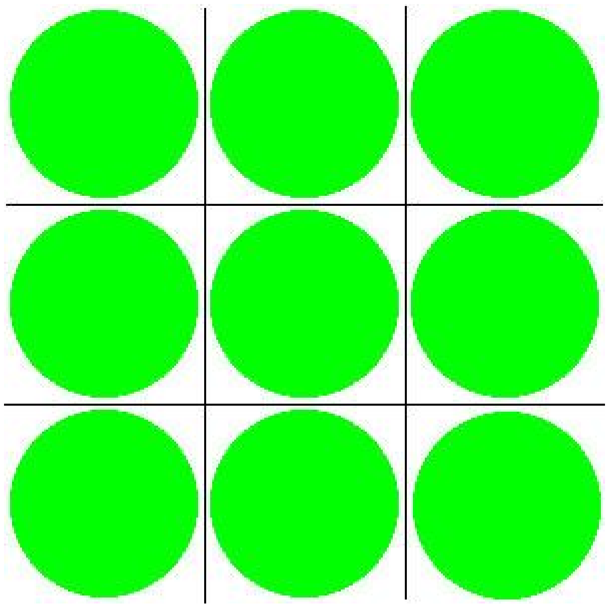

Fig. 2.5. An example template used in stimulus design (not to scale). Individual target and distractor stimuli were created by deleting four or more shapes from the grid above. The same template was used for red circles, green squares, and red squares. The horizontal and vertical lines were not visible to participants but represent the nine standardized regions in which sub-array shapes were located.

Half of the stimuli were targets and half were distractors. The defining property of a target stimulus varied on two dimensions: a target could be identified on the basis its Feature Conjunction (FC), where red squares and green circles were targets and green squares and red circles were distractors, or on the basis of the Number (N) of shapes that the stimulus contained, where three or five shapes constituted a target, and two or four shapes constituted a distractor. N and FC stimuli were represented with equal probability.

Each stimulus contained two, three, four, or five shapes the colour of which (red or green), and the shape of which (square or circle) were the same in a single exemplar. N and FC stimuli were comprised of these numbers of shapes in equal proportions: half being made up from combinations of odd numbers of shapes, half from even numbers. Half of the stimuli contained a shape at their centre, whereas in the remaining half the central location was empty.

The final factor which differentiated between the stimuli was the location in the display at which the shapes were presented: if a stimulus was defined as target or distractor on the basis of its FC, the number of shapes that it contained (2,3,4,or 5) could be presented in one of eight potential configurations depending on whether the central location was blank or not. For FC stimuli, if an odd number of shapes were presented (3 or 5) the central location *never* contained a shape. In this case the shapes would appear along the outside edges in predetermined patterns. For example, two shapes could be aligned along one edge with a third at the mid-point on the opposite edge. The patterns were rotated through 90°, giving four combinations of each once returned to the original position. The same principles applied to FC stimuli when an even number of shapes were presented (2 or 4), except here one shape was *always* located in the central position (see Appendix 8.1 for full breakdown of stimulus factors).

The same logic of shape-location composition applied to N stimuli, except that here red squares or green circles *never* occupied the central location; while for green squares or red circles one of the shapes was *always* in the central position. This meant that some of the patterns of N stimuli differed from FC stimuli because, in the former case, whether a shape was in the centre or not was dictated by its feature conjunction, whereas in the latter the number of shapes present determined if the central position was occupied.

A PC operating with a Pentium 3 processor was used to run the experiment via E-prime software. A chin rest was used to stabilise viewing position at a distance of 70 cm from the screen.

Design

Three independent variables tackled the main hypothesis of this initial experiment. The first will be referred to as Task (1), and had two levels relating to the stimuli used for this experiment. FC stimuli required participants to identify a target on the basis of its Feature Conjunction (with red squares and green circles being targets, and green squares and red circles being distractors), and respond to it depending on the Number of shapes it contained (with keyboard button 1 designated for an even number of shapes, and keyboard button 2 designated for an odd number of shapes). These trial types are therefore referred to as FCN. Conversely, N stimuli required participants to identify a target on the basis of the Number of shapes it contained (targets being defined as stimuli consisting of an odd number of shapes, distractors stimuli consisting of an even number of shapes), and respond to it on the basis of its Feature Conjunction (with keyboard button 1 designated for red circles or green squares, and keyboard button 2 designated for green circles or red squares). These trial types are therefore referred to as NFC. The stimuli define the two different tasks because the configuration of shapes differs according to the stipulations in the Stimuli & Apparatus section, above. The FCN and NFC tasks were manipulated within-groups, with the prediction that responding according to feature conjunction (i.e. with the NFC task) would be hardest.

The second independent variable will be referred to as Block (2), and had two levels relating to the fact that both the FCN and NFC tasks were presented in two equal blocks of 128 trials: block 1 and block 2. Block was also manipulated within-groups.

The third independent variable will be referred to as Training (3); this variable also had two levels relating to whether participants received training for block 2 or not. The FT strategy advised participants that, irrespective of whether the trial block was FCN or NFC, the correct button press corresponded to whether the central region of the stimulus contained a shape or not: if it did, the correct response would always be button 1; if it did not, the correct response would always be button 2. Hence the responses remain the same throughout the experiment but the training strategy reduces the information processing load –once the stimulus has been identified as a target or distractor, FT simplifies the subsequent response judgement. Training was manipulated between groups, with the training group being advised of the response discrimination contingency in between blocks 1 and 2. Any improvement from block 1 to block 2 in the trained group (FT: N = 16) should therefore reflect the utility of the training strategy; while improvement between blocks observed for the untrained group (NT: N = 16) should be due to general practice. The expectation was that the effect of training would be greater than the effect of practice; larger performance gains ensuing for the former.

There were 16 basic trial types for FCN and NFC conditions (two targets [2], two distractors [2]; central position always or never occupied [2]; two numbers or two shapes which obey this rule [2]). There were 512 experimental trials in total, made up from block 1 and block 2 for both the FCN and NFC tasks. One cycle of the 16 basic trial types occurred randomly eight times in each block (thus giving 128 trials per block). For a single trial, one of the stimuli corresponding to that trial type would be selected at random by Eprime.

In order to counterbalance for the potential confounds of order and carryover effects, an ABBA design was employed. Here A_1 refers to the first block of FCN trials and A_2 the second; likewise B_1 refers to the first block of NFC trials and B_2 the second. These were counterbalanced across the training and no training conditions so that four participants from each group underwent $A_1B_1B_2A_2$, $B_1A_1A_2B_2$, $A_1B_1A_2B_2$, and $B_1A_1B_2A_2$, respectively.

Procedure

On arrival informed consent was obtained from the participants. Detailed instructions were available on the computer screen explaining the task, and the experimenter was present throughout to ensure participants understood what they had to do. The experimental procedure for an example FCN and NFC trial is shown in full in Fig. 2.6. Each block of the experiment was preceded by 16 practice trials to allow participants to become accustomed to the task which would follow. Once the experimenter was satisfied the participant understood the task, the participant could proceed to the experimental block following practice.

Participants were asked to respond as quickly and as accurately as possibly. The first judgment to be made was whether the stimulus was a target or distractor. If the stimulus was believed to be a distractor the appropriate response was key 0 on computer keyboard's number-pad. The presentation of distractors served as catch trials to ensure participants carried out both the target identification and subsequent response discrimination tasks. For targets however participants had to respond according to the stipulations outlined n the design section (above); button 1 refers to key 1 on the number-pad, and button 2 refers to key 3 on the number-pad. A debrief questionnaire was completed once finished, collecting feedback about whether the response strategy was noticed.

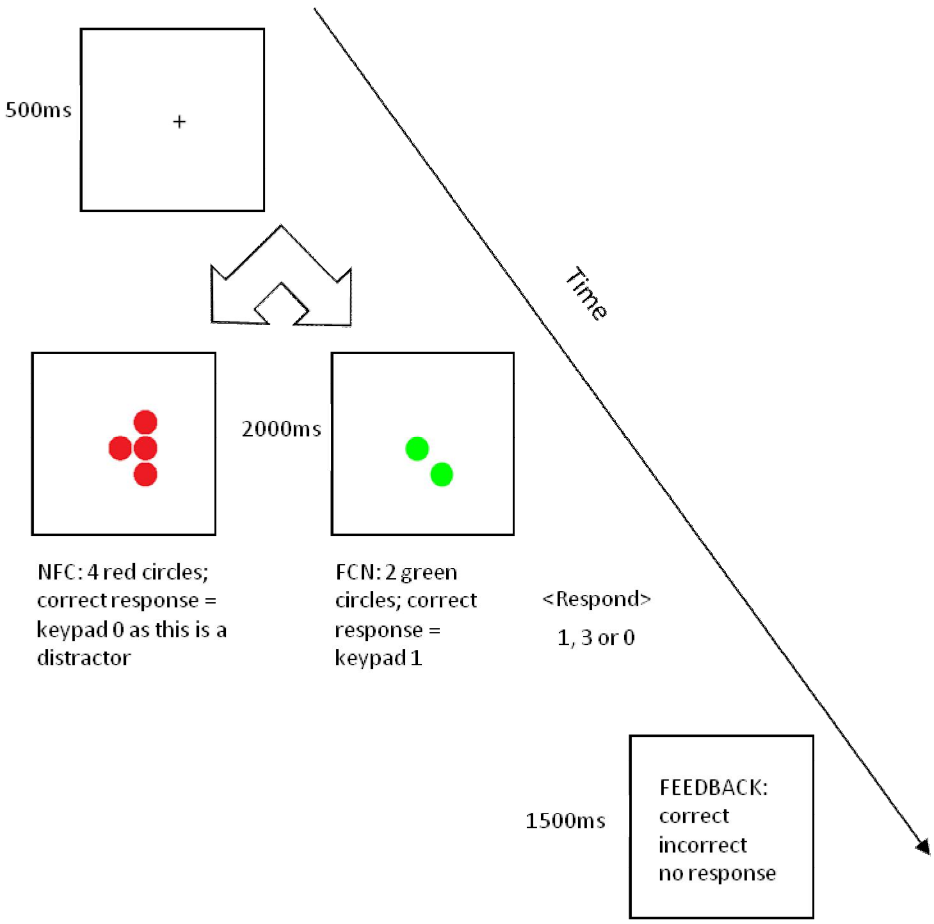

Fig. 2.6. The sequence of events for one experimental trial. Each trial commenced with a fixation cross presented centrally for 500 milliseconds (ms). Then, depending on whether the block was FCN or NFC, a stimulus was presented centrally for 2000ms; participants were required to respond within this temporal window, after which feedback was presented at the centre of the screen for 1500ms as indicated in the figure ('time-outs' were considered incorrect; a response terminated the trial).

2.1.2. Results

Reaction Times

Reaction time (RT) data was collected for both the trained and untrained groups and collated across the four experimental blocks, with practice trials removed. A number of pre-analysis filters were imposed on the RT data. Firstly, responses to distractor stimuli were removed, leaving 256 trials per participant. Also incorrect answers were removed: 12% were incorrect after filtering out responses to distractors. A check was made for anticipatory responses (<200ms), but no responses fell into this category. Independent samples *t*-tests were also used to check groups did not differ from the outset: block one performance in either the FCN or NFC tasks was not statistically different between groups, and this was the case for both dependent measures taken (RT: p's > 0.5; Accuracy: p's >0.05). From the remaining data mean RTs were analysed in a 2x2x2 mixed factorial ANOVA (Training/No Training; FCN/NFC; Block 1/Block 2).

This RT analysis revealed a statistically significant main effect of block (F (1,30) = 73.2, *MSE* = 7519.4, p <0.001) and a significant interaction between block and training (F (1,30) =21.5, *MSE* = 7519.4, p<0.001). These findings reflect an improvement in the second ($\bar{x}$ = 1060ms) relative to the first block ($\bar{x}$ = 1192ms). However, the presence of a significant interaction between block and training reveals that FT improves performance more than exposure alone (see Fig. 2.7 & Fig. 2.8, below), as can be seen by the lower RT's in block 2 when training was provided ($\bar{x}$ = 997ms) compared to when it was not ($\bar{x}$ = 1124ms). The absence of a three way interaction shows that training does not have a differential effect on Task.

Difference scores were also calculated to compare the *relative* changes in performance from block 1 to block 2. For each participant block 1 RT was subtracted from block 2 RT for both the FCN and NFC tasks; therefore a positive value reflects an increase and a negative value reflects a decrease. This transformation has the advantages of controlling for idiosyncrasies between participants, whilst reducing error variance in a standardised way. The difference score analyses yielded effects which mirror those already reported, with the effect of training being greater in magnitude than the effect of practice, both for the FCN (t_{30} = -3.91, p <0.001), and NFC (t_{30} = -3.30, p <0.005) tasks.

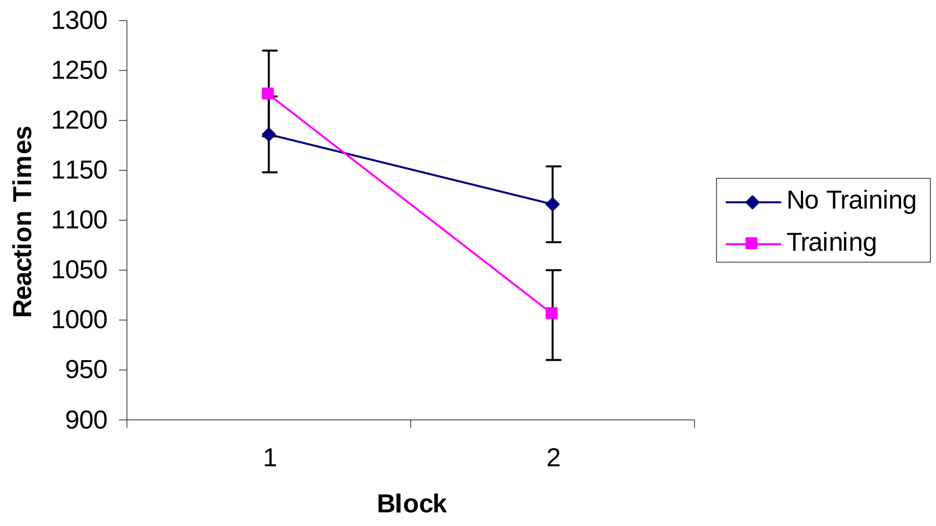

Fig. 2.7. Reaction times (ms) to FCN stimuli in block 1 and 2 for the untrained Fixate trained group. Error bars represent standard error of the mean.

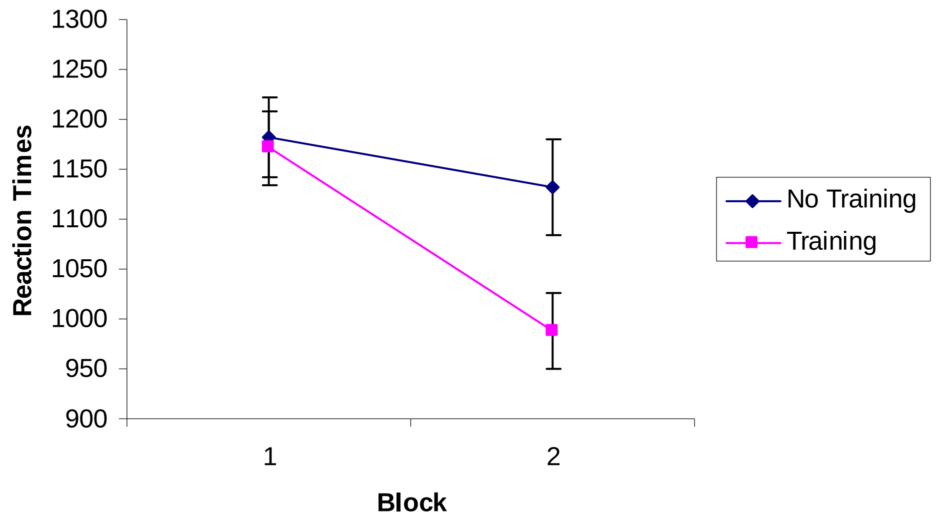

Fig. 2.8. Reaction times (ms) to NFC stimuli in block 1 and 2 for the untrained Fixate trained group. Error bars represent standard error of the mean.

Accuracy

Accuracy data for experimental trials across conditions is shown in Table 2.1. The same factorial ANOVA was conducted as with the RT data. A main effect of block was observed (F (1,30) = 26.0, *MSE* =31.4, p<0.001), indicating participants were more accurate in the second ($\bar{x}$ = 90.5%) compared to the first ($\bar{x}$ =85.4%) block, as with RT's. There was also a main effect of task (F (1,30) = 16.6, *MSE* = 26.3, p<0.001), indicating the lower accuracy of the FCN task ($\bar{x}$ = 86.0%), where participants had to identify targets on the basis of their feature conjunction and respond on the basis of the number of shapes present. The overall accuracy of the NFC task, where participants had to identify targets on the basis of the number of shapes present and respond on the basis of the shapes' feature conjunction, was, in comparison, significantly better ($\bar{x}$ = 89.8%). Correspondingly, there was a significant interaction between task and training (F (1,30) = 7.0, *MSE* = 26.3, p = 0.013), showing that accuracy at the FCN task was assisted by fixate training (NT $\bar{x}$ = 84.3%; FT $\bar{x}$ = 87.9%), whereas for the NFC task the untrained group were already near ceiling (NT $\bar{x}$ = 90.3%; FT $\bar{x}$ = 89.2%). The difference score analysis, although revealing a trend towards training improving accuracy with the FCN task, did not reach conventional statistical significance ($t_{21.96}$ = 1.9, p = 0.077).

Counter to predictions, these results suggest that the FCN task is somewhat more difficult therefore assisted by the training manipulation. It was expected that responding according to the number of shapes displayed would be easier than responding according to their feature conjunction, because it is possible that subitization processes could be relied upon with the former discrimination judgement, whereas attentionally demanding feature integration processes were required with the latter. It may be that the initial target identification stage of the tasks plays a role, with the slightly different constraints imposed on the number and feature conjunction components between the FCN and NFC tasks influencing accuracy in different ways. These issues are addressed in the discussion which follows.

	Block 1		Block 2	
	FCN1	**NFC1**	**FCN2**	**NFC2**
No training	79.8	88.7	87.9	92.8
	2.7	*1.1*	*1.3*	*0.9*
Training	86.0	89.9	88.0	90.5
	1.7	*1.5*	*1.3*	*1.1*

Table 2.1. Percentage correct across conditions for the untrained Fixate trained group. These values represent accuracy when targets and distracters are included. Standard errors are italicised.

2.1.3. Discussion

The results of Experiment 1 suggest that participants can utilise the Fixate training strategy to carry out the response task more easily, as evidenced by the significant reduction in reaction time when made aware of the contingency governing stimulus discrimination. In the absence of eye tracking data one cannot state unequivocally that fixation durations or the time spent dwelling upon stimuli were reduced by the training manipulation, however it is likely that oculomotor statistics would reveal such decreases in processing time. Given that accuracy either increased with or was unaffected by training, it therefore appears that FT improves the efficiency of inspection.

It must be pointed out however that I am aware that the above conclusions depart somewhat from the fixation gating mechanism as conceived in Findlay & Walker's model (1999). The model outlines a framework primarily for understanding *individual* fixations and saccades but here I suggest that *multiple* fixations, when summed across stimulus inspection, will reveal an overall decrease in processing time associated with reduced informational load. However, this conclusion adheres to evidence cited by Findlay & Walker for the *cognitive processing* channel in the WHEN pathway. For example, when scanning for a target letter fixation durations increase with an increase in set size of potential targets memorised (Gould, 1973). While no claims about fixation durations can be made at this stage, even if FT as operationalised here does not reduce their duration, the fact that it reduces the total time spent inspecting stimuli overall suggests an economy with each separate fixation when extracting information. In line with Gould's findings of reduced processing time even though stimuli are kept constant, the results of Experiment 1 suggest a similar decrease in cognitive processing load linked to informational content not physical characteristics.

Clearly however it cannot be claimed that equivalent information is gathered by the FT group compared to the NT group, as the former have no need to process stimuli beyond identifying them as target or distractor. The training strategy simply negates the need to concentrate on complex differences in stimulus attributes pertaining to the response discrimination; therefore it is likely that this information is not acquired by the FT group. We are in the advantageous position here of considering results obtained with stimuli which have been precisely controlled (i.e. the experimenter could advise with absolute confidence that everything else about the stimuli bar the central region could be ignored when responding, and accuracy would still be maintained). However, such a degree of prior knowledge may not be available in naturalistic tasks. I am not suggesting that the FT group apprehend the same information as the NT group but in a shorter amount of time, only that in contexts where the stimulus-response relationship can be simplified by eliminating attention to redundant detail then efforts should be made to do this.

A final point concerns the accuracy data and the relative difficulty of the FCN and NFC tasks. I made the prediction that responding according to feature conjunction would be more challenging than responding according to the number of shapes present, due to feature integration being more attentionally demanding than grouping by number. However, this prediction was not borne out in the data –in fact the opposite seems to have occurred. The accuracy analysis revealed that the *FCN task* (where participants responded with respect to the number of shapes) was more difficult than the *NFC task* (where participants responded with respect to the shapes' feature conjunction). Moreover, training improved performance with the FCN task, while it had no effect upon the NFC task, again a finding that is contrary to expectations. Why might this be the case, and does it rule-out the original predictions I made?

There are several reasons why the FCN task may be more difficult and therefore benefit from FT, and these reasons do not necessarily contradict with the arguments outlined when Experiment 1 was introduced. If we assume that identifying targets on the basis of their feature conjunction is more difficult than making discrimination judgements based on numbers of shapes, as suggested, then once a target has been identified, the discrimination judgement may overload resources which are already stretched to near capacity by the target identification stage. Conversely, NFC targets may be easier to detect because numbers of shapes can be subitized and therefore interfere with the response task less. Moreover, the response required for a number judgement is not comparable for both FCN and NFC tasks. In the latter case the number judgement simply requires a '0' key press only when distracters are presented, however in the former there are two alternative responses based on number *immediately following difficult feature integration to identify the target*. This may explain the results obtained without contradicting previous research upon which my predictions were based: feature conjunctions remain more difficult to interpret than numbers of shapes, but the number judgement required (target or stimulus discrimination), and the order in which this judgement is required (initially or following a difficult feature integration) obscures this fact. Participant self-reports on completion of the study invariably conformed to this interpretation, with people reporting that it was easier [with the NFC task] to quickly identify the target and then proceed with the stimulus response discrimination. (It was also noted upon debrief that no participants reported awareness of the response contingency without being explicitly informed).

In sum I believe the findings from Experiment 1 justify the use of these stimuli with single target presentation task; therefore the next line of enquiry was to evaluate how they can be used in visual search, and how training directed at the Move centre can affect this.

2.2. Experiment 2 - Move Training

Having established that a top down training principle can be successfully applied to stimulus discrimination judgements, the next experiment sought to gain insight into top down control and visual search. How does training people where to look affect search performance?

The same stimuli were used as in Experiment 1 except this time one target was arranged amongst an array of distractors within a 3x3 grid (as in Fig. 2.2). As Experiment 2 tackled MT in isolation the stimulus discrimination judgement (related to FT) was not of paramount importance. Therefore, the FCN and NFC stimuli were divided solely of the basis of the number of shapes they contained, with the criterion defining a target this time being that the stimulus was comprised of an odd number of shapes (3 or 5), while distractors being defined as stimuli consisting of an even number of shapes. Thus feature conjunction was irrelevant in Experiment 2; once a target had been identified a response was still required, but the response did not differ from the criterion defining a target, with one button designated for targets of three shapes, and another for targets of five shapes.

Number of shapes was chosen as the dimension for target categorisation *and* response primarily because, when directing training towards the Move centre independently, I did not want visual search to conflict with stimulus discrimination (by way of competition between the Move and Fixate centres). To this end, because grouping by number may be open to simplification by subitization processes, as suggested, number was used to define targets *and* responses. The rationale behind this design choice should ensure reduced load when scrutinising stimuli prior to a response, thereby inducing less Fixate centre activity.

This is important because the MT strategies in Experiment 2 predicted the location of the target from trial-to-trial (as in Fig. 2.3), and if responding to the target was too difficult the ability to adopt the MT strategy may have been hindered. Hence only one criterion (3 shapes or 5 shapes) was attached to each response (button 1 and button 2 respectively) because this experiment was concerned only with MT in isolation, therefore aimed to minimise influences related to FT. In line with this, because both FCN and NFC stimuli were used but only the number of shapes was relevant, the central region of the stimuli would not conform to any contingency. The discrimination judgement should be easier than in Experiment 1 by default, and there was no strategy which could be deduced that would simplify it further.

The specific MT strategies used in this experiment are shown below (Fig. 2.9); these were pitted against random target presentation as a control comparison, with the expectation that employing any of the MT strategies would dramatically improve visual search. The strategies were selected to assess MT with increasing complexity:

the ‘egg-timer’ pattern possibly being the most difficult to implement, and the ‘square’ pattern possibly being the easiest. If this is correct then the largest training advantage should be seen with the ‘square’ pattern and the smallest training advantage should be seen with the ‘egg-timer’ pattern. Given that I am explicitly informing participants of the location of the target in this experiment, the effects of training should be most pronounced in the RT measure.

2.2.1. Method

Participants

Twenty naïve paid participants (10 female) were recruited from the University of Nottingham’s student population and surrounding local area (mean age 26yrs, range 19-39). All participants reported normal or corrected-to-normal vision.

Stimuli & Apparatus

The same stimuli were used as in experiment 1 but were divided into target and distractor solely on the basis of the number of shapes the stimulus contained, thus rendering the FCN/NFC distinction irrelevant. Targets were defined as stimuli comprised of an odd number of shapes (3 or 5), conversely distractors were stimuli comprised of an even number of shapes (2 or 4). Hence, 128 stimuli corresponded to the target criterion, and 128 to the distractor.

Whereas in experiment 1 a single stimuli exemplar was presented in each trial, in Experiment 2 eight stimuli were presented on the screen at a time, each occupying one of 8 equally proportioned square locations of a 3x3 grid –the search array (cf. Fig. 2.2). The central location of the search-array was always blank which necessitated search around the periphery, thereby encouraging eye movements. The grid was 933cm^2 and subdivided by four visible black lines, which created sectors approximately equal to 104cm^2 each –the sub-array. This meant that stimuli of the sub-array were reduced in size from Experiment 1 by a factor of approximately 2.5 to fit into their position in the search-array grid.

As previously, a PC operating with a Pentium 3 processor was used to run the experiment via E-prime software. Stimuli were presented on a 21″ FD Trinitron CRT monitor, and a viewing distance of 70cm was stabilised with a chin rest.

Design

Two independent variables addressed the main hypothesis. First, the Sequence (1) of locations in the search-array that the target could appear in was manipulated (Fig. 2.9). There were three patterns, repeated every four trials, which dictated where the target would be presented with 100% probability: (i) a Square Pattern (Fig. 2.9: left panel), which dictated that the target would always be presented in the bottom left sector of the grid, then the top left sector, then the top right sector and finally the bottom right sector, across four trials; (ii) a Diamond Pattern (Fig. 2.9: centre panel), which predicted that the target would always appear first in the left middle sector, then top middle, followed by right middle, and lastly bottom middle, across four trials; (iii) an Egg-timer pattern (Fig. 2.9: right panel), which predicted the target would always be presented in the bottom right grid sector, followed by the top left, then the top right, and lastly the bottom left, across four trials. All patterns cycled continuously and the order of target presentation was never broken. A random pattern was also used, in which case the position that the target would appear in was unpredictable. The sequence variable therefore has four levels (square, diamond, egg-timer, random) which all participants underwent in a random order.

The second independent variable was Training (2). As with Experiment 1, training was manipulated between groups, with half of the participants being made aware of the patterns of target presentation, and half never having the patterns revealed to them. The training variable thus has two levels, MT and NT respectively.

There were four basic trial types, one for each level of the sequence variable, and four experimental blocks. One of the sequences was selected at random and cycled throughout a block, and this process was repeated until all sequences were used. The mean for each level of the Sequence variable was taken from 128 trials per block. In a single trial one of the 128 stimuli corresponding to the target definition (an odd number of shapes) was selected at random by Eprime and presented in the grid sector determined by the sequence. With the random pattern, as there are eight potential stimulus locations in the grid, a target would therefore appear in each position of the grid sixteen times. For the remaining patterns only four positions in the grid could contain a target, therefore when broken down across the 128 trials a target would appear in each of those four positions thirty-two times.

Distractor stimuli (stimuli comprised of an even number of shapes) occupied all seven of the remaining grid sectors which did not contain the target. Of the 128 distractor stimuli a different combination of distractors in each position was selected pseudo-randomly for every trial.

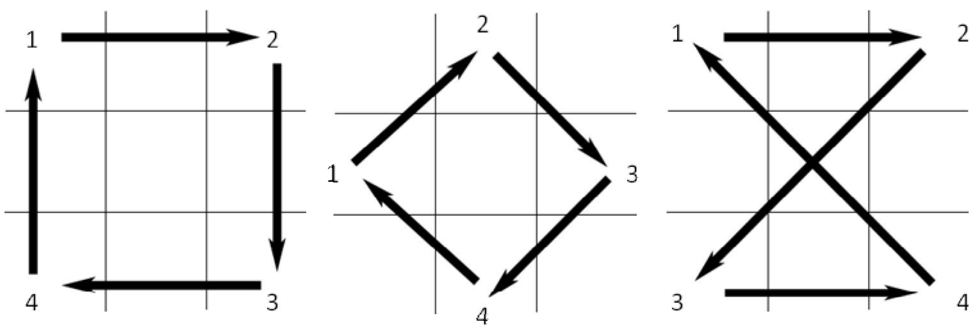

Fig. 2.9. Patterns of target presentation for the MT group. Numbers indicate the target location in sequence; arrows indicate the upcoming target location in the next trial, and are superimposed to highlight the pattern only. The figure does not represent a single display.

Procedure

Prior to commencement of the experiment informed consent was obtained. Detailed instructions were available on the computer screen throughout, and the experimenter was always present to clarify any uncertainties about the task.

Each sequence had an equal probability of being selected for the first, second third or fourth block of trials. In each trial a fixation cross was first displayed for a duration of 500ms, then the grid appeared containing the stimuli for 2500ms. Participants were required to find the target within this time window and respond with button 1 (1 on the keyboard's number pad) if the target contained 3 shapes, or with button 2 (3 on the number pad) if it contained 5. Feedback was presented at the centre of the screen as in Experiment 1 ('time-outs' were considered incorrect; a response terminated the trial). Participants were asked to respond as quickly and as accurately as possible.

Prior to each block the MT group were allowed 20 practice trials to become accustomed with the strategy to be used in the block which would follow. Trial selection during practice was identical to the proceeding block (therefore prior to the random block practice served as a filler). Twenty 'dummy' trials were adjoined each experimental block for the NT group to ensure equal exposure to the task. The transition was seamless between 'dummy' and experimental trials. As in Experiment 1 a debrief questionnaire was completed once finished.

2.2.2. Results

Reaction Times

Practice and 'dummy' trials were removed before analysis for all analyses described. Reaction time data were recorded for the MT and NT groups and extracted for each of the four experimental blocks corresponding to the four patterns of target location. No participants responded too early (<200ms), showing that responses made did not overlap trials. Incorrect responses were removed from the RT analysis (14%). Following this data filtering the remaining results were subjected to a 2x4 mixed factorial ANOVA, with Training as the between-groups factor with two levels, and Sequence as the within-groups factor with four levels.

The analysis revealed a statistically significant main effect of training (F (1,18) = 56.5, *MSE* = 39605.6, p <0.001); with a consistent advantage of faster RT's to targets when training was available ($\bar{x}$ = 853ms), compared to when it was not ($\bar{x}$ = 1522ms). There was also a main effect of sequence (F (3,54) = 32.9, *MSE* = 31666.8, p <0.001); with the random sequence leading to the slowest RT's ($\bar{x}$ = 1528ms) and the remaining sequences speeding up search by 453ms on average. Ascending planned contrasts showed that the square sequence did not differ from the diamond, and the diamond did not differ from the egg-timer (p's > 0.5). However, the main effect of sequence is driven by an interaction between sequence and training (F (3,54) = 28.3, *MSE* = 31666.8, p <0.001). This demonstrates that when MT is tailored to the location of target presentation in sequence a very substantial benefit is found (see Fig. 2.10). This advantage moreover, occurred irrespective of variations in sequence: planned contrasts of the interaction term showed no significant differences between groups for the square vs. diamond sequence (p = 0.9), or diamond vs. egg-timer sequence (p = 0.3). It therefore appears that the sequences chosen were equated in terms of difficulty, or rather, utility when made aware of them.

It is also important to point out here that upon debrief only one of the untrained participants explicitly reported noticing patterns (they realised the diamond sequence right at the end of the block, and subsequently worked out the square sequence in the following block at the beginning. This explains the slight dip, and increase in variance, in Fig. 2.10 for the untrained group with the square sequence.) Neither does it seem that there was any *implicit* awareness of the sequences, because reaction times of the NT group were no faster when the target appeared in a predictable order than when presentation was random. It is quite striking that even with 128 trials exposure only one participant realised that there were contingencies relating to the location of targets.

As no block 1 was incorporated into the design[1] of Experiment 2, it is not possible to calculate difference scores as in the first experiment. However, because the magnitude of the training effect is so large, and both groups performed comparably with the random pattern (as assessed with an independent samples *t* – test; p > 0.7), it is reasonable to conclude that the effects observed are due to the top down strategy employed by the MT group.

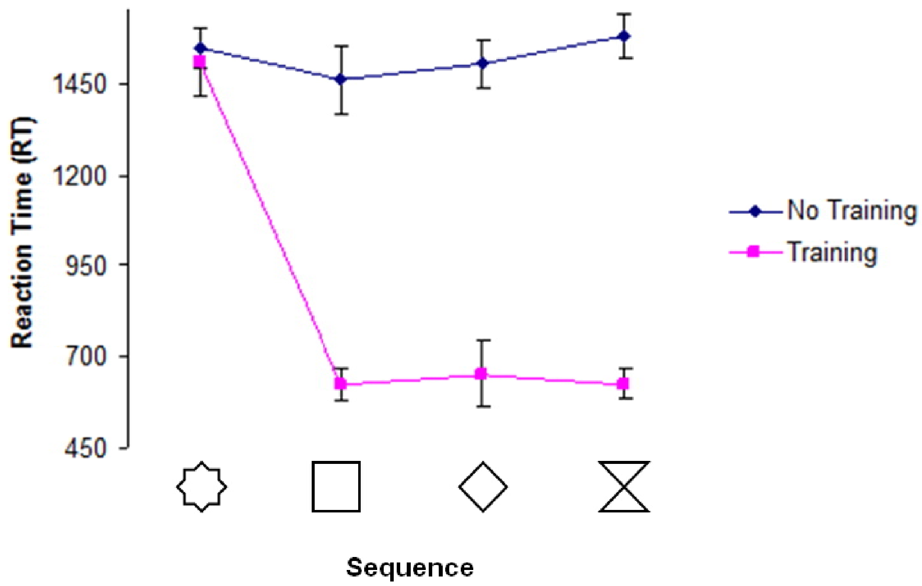

Fig. 2.10. Reaction times (ms) for the untrained and Move trained group across each level of the sequence variable (left to right: random, square, diamond, egg-timer on the *x* axis). Error bars represent standard error of the mean.

[1] The reasons there was no block 1 were partly pragmatic (to include a block 1 would double the number of trials in the design to 1024), and partly statistical (all sequences would be compared to random presentation anyway).

Accuracy

Accuracy was very high in Experiment 2 for both groups of participants (see Table 2.2). The accuracy data was analysed with the same ANOVA used for RT's, and the effects were comparable. A main effect of training was observed ($F(1,18) = 37.41$, *MSE* = 53.05, $p < 0.001$); as well as main effect of sequence ($F(3,54) = 23.55$, *MSE* =28.81, $p<0.001$); and these two variables significantly interacted ($F(3,54) = 16.38$, *MSE* = 28.81, $p < 0.001$). This indicates an MT advantage in terms of accuracy also, with groups performing comparably with the random sequence (as assessed with an independent samples *t*-test; $p > 0.1$), and accuracy increasing considerably when informed of any of the predictable orders of target presentation. The same repeated contrasts showed no differences between the square and diamond, or diamond and egg-timer sequences, either for the simple main effect, or the interaction term (all p's >0.1).

	Sequence			
	Random	**Square**	**Diamond**	**Egg-timer**
No Training	80.00	84.22	83.13	78.52
	2.5	*2.4*	*1.6*	*2.3*
Training	75.86	97.27	95.94	96.64
	1.9	*0.7*	*2.0*	*0.9*

Table 2.2. Percentage correct across each level of the sequence variable for the untrained and Move trained group. Standard errors are italicised.

2.2.3. Discussion

The main prediction of Experiment 2 was that MT would dramatically improve search times, and the results show this is correct. There was also a substantial effect of training on accuracy which complements the RT data. The different MT sequences used were chosen to assess whether some patterns of target presentation are harder to follow than others, but at least with the sequences used here this does not appear to be the case. It is likely that if the chain making-up one iteration of a sequence was longer, or if the spatial locations were more constrained, the ability to implement MT would be impaired. However as it stands, Experiment 2 shows that MT alone significantly improves visual search performance. This allows one to progress with experiments which combine MT and FT in the knowledge that any of the sequences used here can be useful. Moreover, Experiment 2 also provides assurance that even simple eye *movement* strategies are not easily guessed in this paradigm by an uninformed NT group.

2.3. Experiment 3a - Move & Fixate Training in concert

The next experiment in this series addressed whether the influences of Move and Fixate training, observed independently in the first two experiments, could be combined to give an additive training advantage attributable to each aspect of the task: visual search and stimulus discrimination. The same search-array was used as in Experiment 2, but this time all features of a complete stimulus set were relevant. The FCN sub-array stimuli described in section 2.1.1 were displayed to participants within the overall search-array grid. Participants were required to scan the grid for red square or green circle targets amongst green square and red circle distractors. Once located, responding to the target sub-array required a discrimination judgement about how many shapes the target was comprised of –one button designated for an even number, another button for an odd number (as in Experiment 1). Training could therefore be directed towards the Fixate centre in the same way as previously (i.e.

with reference to the central location of the sub-array: see Fig. 2.4), but this time training could *also* be directed towards the Move centre, as in the last experiment.

The primary reason this stimulus set was chosen to assess Move and Fixate training in concert to begin with was that although FT reduced response latencies for both stimulus types (i.e. FCN *and* NFC) in Experiment 1, the accuracy data suggested that training was more beneficial when responding according to the number of shapes (i.e. with FCN stimuli). Although I argued in section 2.1.3 that this does not necessarily conflict with accounts of perceptual grouping and feature integration (one might expect numerical judgements to be easier through subitization, therefore benefit less from training than colour-shape discriminations), it seemed prudent to first test combined training in the visual search paradigm beginning with the stimuli most likely to yield an additive training advantage based on previous results.

There were four groups of participants in Experiment 3a: No Training, Fixate Training, and Move Training, as previously, with the addition of a training group made aware of *Both* the visual search *and* stimulus discrimination contingencies (Both Training [BT]). Because the most complex MT pattern from Experiment 2 (the egg-timer sequence) aided visual search as much as more obvious sequences, this pattern of target presentation was used in the present Experiment[2], with Move trained participants being made aware of the predictable order. The FT group were not informed that target locations were foreseeable; their training was confined to the response discrimination, as in Experiment 1 (i.e. checking the stimulus' centre within the sub-array to reduce processing demands; see Fig. 2.4). The BT group were advised to move their eyes in the egg-timer pattern from one trial to the next and, on

[2] Note that one participant worked out the diamond, and subsequently square, patterns of target presentation in Experiment 2 (see section 2.2.2). The aim was to reduce the possibility of participants guessing the experiment's contingencies here, thus maximising the benefit of training. Hence the most complex MT sequence was chosen.

foveating the target, focus on its central region to ease the difficulty of the response judgement.

In Experiment 2 the stimulus discrimination judgement on responding was simplified (with only one criterion relating to each response) to assist with adopting the MT scanpath by reducing potential competition between the Move and Fixate centres at the end of a trial. However, having established that MT independently can be an advantage, this experiment included the taxing double criterion responses of FCN stimuli to see whether the urge to move the eyes to the upcoming target location (sub-served by the Move centre) hindered the ability to process the stimulus prior to responding (sub-served by the Fixate centre). It is by such a process of reciprocal inhibition that a harmonious relationship between fixations and saccades is maintained in Findlay & Walker's (1999) model.

The main hypothesis therefore predicts an additive training advantage evident in the RT data, with NT leading to the worst performance and BT the best, in increasing increments across groups. However, it is also plausible that the 'push-pull' relationship between the Move and Fixate centres will decrease the accuracy of the MT group in the manner alluded to in the previous paragraph.

2.3.1. Method

Participants

Sixty one naïve paid participants (44 female) were recruited from the University of Nottingham's student population and surrounding local area (mean age 22yrs, range 18-57 [note that only one subject had an outlying age, of 57yrs, the rest were grouped around the mean]). All participants reported normal or corrected-to-normal vision.

Stimuli & Apparatus

The same FCN stimuli were used in Experiment 3a as in Experiment 1. Therefore targets were defined on the basis of their feature conjunction, with red squares and green circles being targets, and green squares and red circles being distractors. As before, responses to FCN stimuli are defined on the basis of the number of shapes the stimulus contains. One hundred and twenty eight stimuli make up this stimulus set.

As in Experiment 2, eight sub-array stimuli were presented on the screen at a time, each occupying one of eight equally proportioned square locations of the same 3x3 search-array grid used previously. The centre location of this grid never contained a stimulus, thereby encouraging eye movements. Only one target would be presented in the search-array for each trial, the remaining 7 locations of the grid would contain distractors.

The same PC, monitor, software and chin rest set-up was used.

Design

Two independent variables addressed the main hypotheses. The first was Block (1) and is divided into two levels which refer to the first half and second half of the experiment for each participant. Thus, block 1 and block 2 both consisted of 128 trials.

Whereas the former independent variable was manipulated within-groups, the second (Training [2]) consisted of four between groups conditions: NT ($N = 16$), FT ($N = 16$), MT ($N = 16$), and BT ($N = 13$). During block 1 none of the participant groups were informed of any of the contingencies to which stimulus presentation adhered (though these contingencies were respected throughout the experiment). During block 2 participants were informed of the principles governing the stimuli depending on which training group they belong to. The NT group were not given any hints to improve their performance therefore any improvements observed in block 2 are due to practice alone. The FT group were advised to look to the central region of the target sub-array to help with the response judgement, as described in section 2.1.1 and depicted in Fig. 2.4. The MT group were made aware that targets would predictably occur in the in the pattern dictated by the egg-timer sequence (Fig. 2.3 & Fig. 2.9: right panel). Finally, the BT group were informed of the egg-timer sequence to aid visual search, *and* the central shape contingency to aid stimulus discrimination.

Because the egg-timer sequence determined target presentation throughout, a target appeared in each corner sector of the grid thirty two times in block 1 and block 2. Half of the FCN stimuli conform to the target definition (red squares/green circles) hence one of 64 potential targets was randomly selected in each trial. Distractors were likewise drawn from the 64 stimuli that comprised the distractor set (green squares/red circles): for each trial the combination of distractors occupying the remaining seven locations which did not contain the target was selected pseudo-randomly.

__Procedure__

As previously, informed consent was obtained from participants on arrival. Detailed instructions were available on the computer screen and the experimenter was present throughout to ensure participants completed the task properly.

Prior to commencement of the block 1 participants were allowed two separate blocks of 20 practice trials. The first block of practice trials allowed participants to become accustomed to recognising and responding to targets with single stimulus presentation; therefore these trials were identical to the FCN trials of Experiment 1. In the second block of practice trials targets were presented in the 3x3 grid along with distractors. Trial selection and the grid display during this practice were identical to the main part of the experiment with the exception that target locations were randomised. This minimized the possibility that participants would look for a pattern from the outset. Structuring practice in this way helped ensure participants understood the requirements of the task step-by-step. Once the practice blocks were completed and the experimenter was satisfied participants understood what they had to do the experiment proceeded to block 1.

For the first, and only the first, experimental trial a fixation cross was displayed for a duration of 500ms, then the grid appeared containing the stimuli for a maximum of 4000ms. The duration of the stimulus array was longer than in Experiment 2 because the task is harder (i.e. the criteria for search and response are distinct, and the response task is considerably more challenging). Participants were required to find, and respond the target (red squares/green circles) within the presentation window. Trials were terminated upon response. Button 1 (1 on the keyboard's number pad) was the correct response if the target consisted of 2 or 4 shapes; Button 2 (3 on the keyboard's number pad) was the correct response if the target consisted of 3 or 5 shapes, as in Experiment 1. Feedback was provided at the end of a trial by way of blue (incorrect) or red (correct) transient screen which masked the display for 200ms ('time-outs' were considered incorrect). This modification to how feedback was provided rectifies a minor issue with Experiment 2. In Experiment 2 text was presented centrally as feedback ("correct"/"incorrect"); therefore it is unlikely participants moved their eyes to each location of the MT sequences in turn; rather, all participants probably moved their eyes back to the centre of the screen in between each trial. The change to feedback presentation in this experiment helps ensure that feedback does not interrupt following the patterns of target presentation, and in line with this should reduce attention capture by masking transient changes in the display (cf. Simons, 2000). Trials were selected according to the stipulations in the design section (above), and the presentation of a search-array followed by feedback continuously cycled until the end of a block. Participants were asked to respond as quickly and accurately as possible throughout.

After completion of block 1 on screen instructions advised participants of the respective training strategy(ies) to adopt for block 2, depending on the training group to which the participants had been allocated (the NT group were told to carry on the task as before). A further twenty practice trials to become familiar with using the training strategy(ies) followed before commencement of block 2. After this practice the experimenter clarified any uncertainties about the training strategies if necessary, and allowed the participant to proceed if they demonstrated a suitable understanding. Twenty dummy trials, with stimulus selection identical to the following block, were adjoined to block 2 for the NT group –the transition was seamless and uninterrupted between these trials and the experimental trials. This inclusion guarantees equal exposure to the task. On completion of block 2 a debrief questionnaire was completed which asked questions pertaining to the task, in particular whether the contingencies were noticed without training. A testing session for one participant lasted approximately 1hr, roughly ⅓ longer than the previous experiments described.

2.3.2. Results

Reaction Times

Reaction time data was extracted from the data set for each of the two experimental blocks across all four training conditions. A negligible amount of responses (0.38%) were anticipatory (<200ms) and were thus were removed prior to all analyses described. Only correct responses were included in the RT analysis (12.2% of responses were incorrect).

Reaction time data was entered into a 2x4 mixed factorial ANOVA with two levels of Block and four levels of Training. A significant main effect of block was observed (F (1,57) = 649.3, *MSE* = 29883.3, p<0.001) which reflects the lower mean RT for block 2 ($\bar{x}$ = 1428ms) compared to block 1 ($\bar{x}$ = 2205ms). Further, there was a main effect of training (F (3,57) = 16.42, *MSE* = 109488.9, p <0.001); with the NT and FT groups performing comparably ($\bar{x}$ = 1982ms; $\bar{x}$ = 2041ms, respectively) and the MT and BT showing a similar training advantage overall ($\bar{x}$ = 1546ms; $\bar{x}$ = 1669ms, respectively). Crucially however, the above main effects are driven by a significant interaction between block and training (F (3,57) = 53.0, *MSE* =29883.3, p <0.001); with differential performance in block 2 as a function of training group (Fig. 2.11).

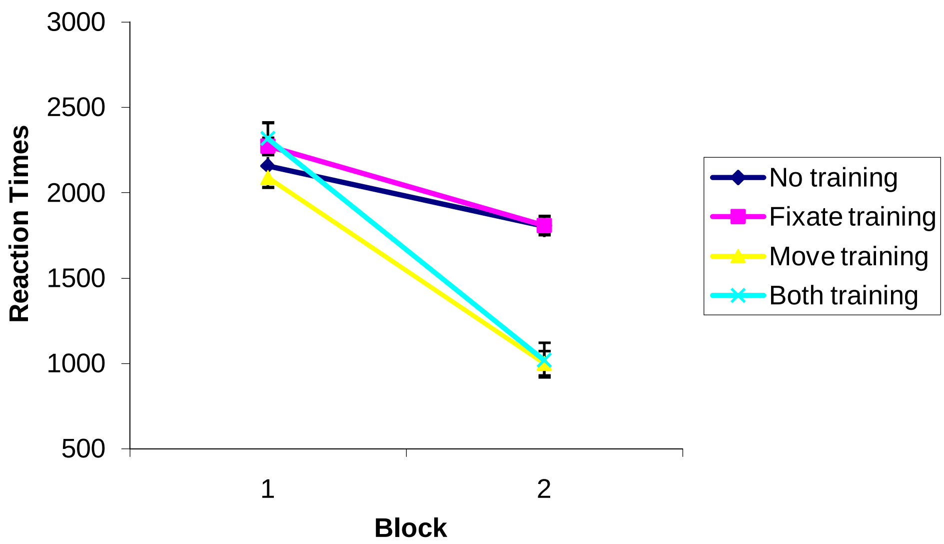

Fig. 2.11. Reaction times (ms) in block 1 and 2 for each training groups. Error bars represent standard error of the mean.

In order to assess the relative effectiveness of each training strategy in relation to the interaction found, difference scores were calculated as in Experiment 1 (by subtracting block 1 from block 2). These data were then analysed using a one-way ANOVA with Training strategy as the grouping variable. This analysis was significant (F (3,57) = 53.0, *MSE* = 59766.6, p<0.001), and Tukey's HSD post-hoc comparisons confirmed that the improvement of the MT group was larger than that of the NT and FT groups (both p's <0.001), as was the improvement of the BT group (both p's <0.001); the NT vs. FT comparison was not significant (p = 0.566), nor was the MT vs. BT (p = 0.117). This indicates that Fixate training, either when implemented independently or in concert with Move training, does not reduce stimulus processing time in the current experiment when carrying out the response discrimination for FCN stimuli. Move training on the other hand leads to large gains in locating the target, irrespective of whether it is used alone or together with Fixate training (Fig. 2.12). (It was also noted that upon debrief no participant spontaneously noticed either of the training contingencies).

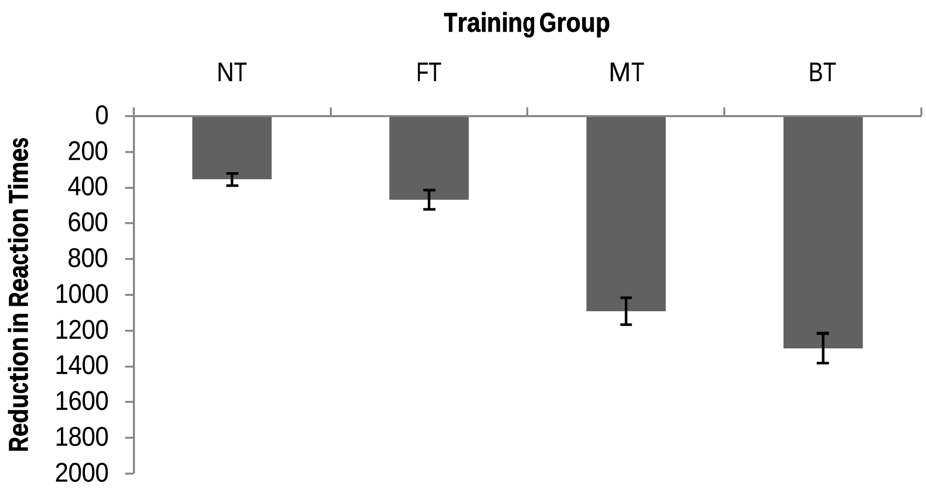

Fig. 2.12. Reaction time decrease (ms) from block 1 to block 2 for each training group. Errors bars represent standard error of the mean.

In accordance with previous analyses, a check was made to establish performance between groups was well equated before training. This is particularly important when dealing with difference scores calculated from two trial blocks which occur in a fixed order, as if a particular group has a quasi advantage from the outset this could obscure the true effect of the training manipulation. Block 1 RT's did not differ between groups as assessed by a one-way ANOVA with training as the grouping variable ($p > 0.05$). This was also true of the accuracy data ($p = 0.67$), which I turn to next.

Accuracy

The only statistically significant effect when the above analysis was repeated with the accuracy data was a main effect of block ($F(1,57) = 59.1$, *MSE* = 53.1, $p<0.001$), which would be expected due to general practice. Therefore, although the greatest improvements in accuracy from block 2 to block 1 can been seen in the MT and BT groups (11% and 15% respectively), these do not significantly differ from the improvements observed in the NT and FT groups (8% and 6% respectively). (See Table 2.3 for the absolute means broken down in full). Therefore, although the direction of accuracy scores mirrors that of RTs, statistically, training improves performance in terms of RTs only, not accuracy. This is because without training the NT group approach ceiling at block 2 due to practice alone. Therefore finding a target defined by its feature conjunction and responding to it on the basis of the number shapes can be performed correctly, if more slowly, without training. As such, the one-way ANOVA, and subsequent post-hoc tests on the difference scores, did not yield any significant effects with the accuracy data.

A final point regarding accuracy concerns the subsidiary prediction that competition between the Move and Fixate centres at the end of each trial may worsen performance of the MT group. Clearly, this speculation is not supported here. This may be because responding according to the number of shapes can be achieved effectively in the search-array paradigm without training, therefore Move–Fixate conflict is not sufficient engender a performance detriment when trained with MT alone. This issue of task difficulty is addressed in the discussion which follows.

	Block 1	Block 2
No Training	83.1	91.2
	3.5	*3.0*
Fixate Training	85.6	91.9
	3.0	*1.7*
Move Training	82.3	93.6
	2.7	*1.2*
Both Training	80.0	95.1
	3.2	*2.3*

Table 2.3. Percentage correct in block 1 and 2 for each of the training groups. Standard errors are italicised.

2.3.3. Discussion

Why was Fixate training unsuccessful in obtaining a performance benefit for the stimulus discrimination judgement with FCN stimuli in the current experiment, while it was successful in Experiment 1? One potential explanation is that during the single stimulus presentations of Experiment 1 participants could maintain a covert focus on the centre of the display in order to utilize the central region rule, while target identification could be accomplished with minimal eye movements. With the current experiment however, the ability to implement Fixate training may be more visually taxing as simply concentrating attention on the centre of the screen will not work. If this explanation is correct it should apply irrespective of whether the response discrimination involves recognising shape integers or feature conjunctions (i.e. with either FC*N* or N*FC* stimuli respectively).

An alternative possibility, however, is that the number discrimination in the present study can be achieved well enough without Fixate training; therefore the training benefit is negligible. This does not necessarily contradict the finding of a Fixate training advantage in Experiment 1 if one considers that the RT measure in the present study is swamped by a general increase (and increase in variance) due to the need to first locate the target prior to responding. Fixate training may still help with the response task (indeed this is the trend with the RT data), but not enough for its effects to be distinguished from general practice with FCN stimuli in the search-array paradigm.

It was argued when introducing Experiment 1, and later when discussing the results (section 2.1 and 2.1.3, respectively), that the aspects of the task which require awareness of the number of shapes present may be easier because participants can rely on subitization processes of grouping by proximity and similarity (cf. Duncan & Humphreys, 1989; Logan, 1996). However, this distinction was less clear in Experiment 1 because the numerical judgements in the FCN and NFC tasks were different (the former required a two alternative forced-choice immediately after a demanding feature conjunction target discrimination, while the latter only required a target present judgement). Within this framework therefore it is still possible to accommodate feature conjunction aspects of the task being harder than numerical categorisations, as should be the case according to the literature (Treisman & Gormican, 1988). If one assumes that in Experiment 1 the initial target identification based on number (i.e. with NFC stimuli) was much easier than when target identification was based on feature conjunction (i.e. with FCN stimuli), but that in the grid array target *search* on the basis of either of these components is equally difficult, then the natural difference between the *response* judgements should fall out. Stimulus discriminations based on feature conjunctions should be harder, and therefore benefit more from Fixate training; number discriminations less so, as observed in the present study. Therefore the next experiment will test the above speculations with the same paradigm as Experiment 3a, but this time using NFC stimuli.

2.4. Experiment 3b - Move & Fixate Training in concert: The affect of task

The methodology of the final experiment of this chapter is identical to last study described: the search-array paradigm was used, except NFC stimuli were presented. Therefore the only difference is task; training was operationalised in the same way as before, with four groups, NT, FT, MT, and BT. When untrained in block 1 (or throughout for the NT group) the task required participants to first locate a uniquely defined target on the basis of its number of shapes (sub-arrays of 3 or 5 shapes being targets), then to respond to it on the basis of its feature conjunction (with one button press designated for red circles and green squares, and a different button press designated for green circles and red squares) as in Experiment 1. Move training advised that the location of the target in the grid was predictable from trial-to-trial, as prescribed by the egg-timer pattern; Fixate training advised that the correct response to red circles and green squares always held to the rule that the stimulus' central region would contain a shape, while this was never the case for green circle or red square targets; with combined Move and Fixate training participants were informed of both of these contingencies.

As the stimulus discrimination judgement on responding pertains to feature conjunctions in Experiment 3b, and such feature integrations should be very attentionally demanding (Treisman, 2006; Wolfe et al., 1989), performance gains are expected which can be credited to Fixate training, either independently (with the FT group) or supplementary to Move training (with the BT group).

Also, given the argument outlined when discussing the previous experiment (section 2.3.3), if the target identification aspects of both the FCN and NFC tasks are equated in the visual search grid, and the greater difficulty of processing feature conjunctions relates only to the stimulus discrimination judgement on responding, then one should observe slower reaction times in block 1 with Experiment 3b compared to Experiment 3a. Moreover the relative changes in RT's following Move or Fixate training should reflect both the search and response aspects of the task separately. Therefore it is possible to estimate any changes in these components between experiments, so if the change in task affects visual search or stimulus discrimination it should be possible to discern this.

The main hypothesis therefore concerns additive training advantages which should be evident owing to the change of Task in the present experiment. However, a secondary prediction is linked to the first hypothesis: If responding according to feature conjunction is more visually and cognitively challenging then it is possible that this will induce competition between the Move and Fixate centres at the end of each trial when participants are directed with MT in isolation. The 'push-pull' mechanism for maintaining equilibrium between the Move and Fixate centres (Findlay & Walker, 1999) may express this competition in terms of an impediment with the response discrimination (reflected by a decrease in accuracy); however it is also conceivable that a diminished ability to execute the MT scanpath will be observed (reflected by a smaller RT decrease for the MT group than we have seen in the last two experiments). Either way, Fixate training should abolish any negative consequences associated with training the Move centre independently.

2.4.1. Method

As the only difference between the methods of this experiment and those of Experiment 3a was the use of NFC stimuli as opposed to FCN, specific details are not repeated again here. The task is described above, and new participants were recruited to perform it as detailed below.

Participants

Forty naïve paid participants (27 female) were recruited from the University of Nottingham's student population and surrounding local area (mean age 25yrs, range 19-33). All participants reported normal or corrected-to-normal vision. The sample size of each training group was uniform (*N* = 10), and assignment was random as previously.

Four participants were replaced (one female from the NT group, one male and one female from the FT group, and one male from the MT group) because they did not complete the task properly; with accuracies ≥ 5 standard deviations below their group mean. These participants were substituted with four females aged 32, 24, 21 and 30yrs.

2.4.2. Results

Reaction Times

Reaction Time (RT) data were extracted from the data set for each of the two experimental blocks across all four training conditions. Again a check was carried out for anticipatory responses (<200ms), so that one could be sure that responses made were to the present trial. A tiny amount of trials fell into this category (0.39%) and thus were removed from all subsequent analyses. Only correct responses were included in the RT analysis (25% of responses were incorrect).

Reaction time data were analysed the same way as in Experiment 3a, using a 2x4 mixed factorial ANOVA with two levels of Block, and four levels of Training. A significant main effect of block was observed (F (1,36) = 869.8, *MSE* = 19996.0, p <0.001), reflecting the lower mean RT in block 2 ($\bar{x}$ = 1758ms) compared to block 1 ($\bar{x}$ = 2691ms). Further, there was a significant main effect of training (F (3,36) = 55.4, *MSE* = 82558.1 p <0.001), evident in terms of the MT and BT groups ($\bar{x}$ = 1816ms; $\bar{x}$ = 1806ms, respectively) performing considerably faster than the NT and FT ($\bar{x}$ = 2647ms; $\bar{x}$ = 2631ms, respectively) overall. Crucially however there was a significant interaction between block and training (F (3,36) = 163.51, *MSE* = 19995.95, p <0.001), which reveals differential performance at block 2 depending on the type of training applied (see Fig. 2.13).

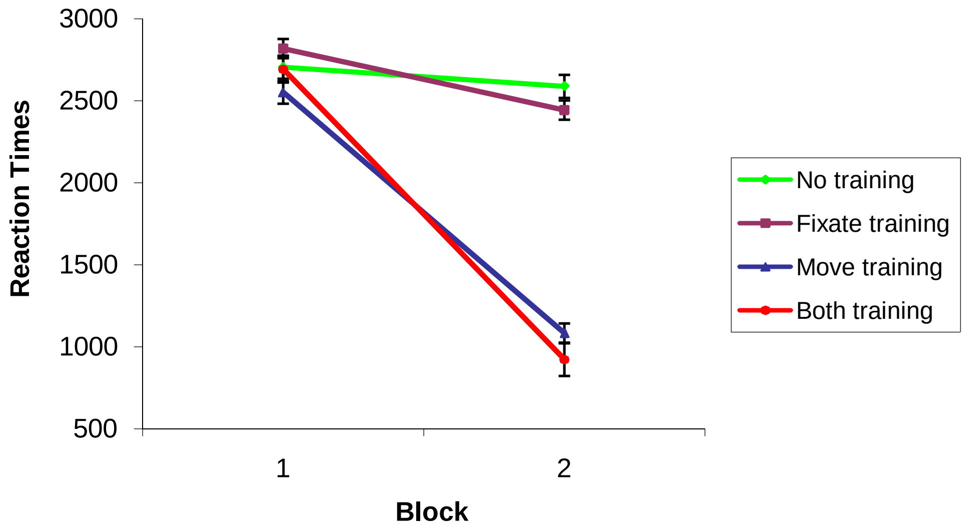

Fig. 2.13. Reaction times (ms) in block 1 and 2 for each training group. Error bars represent standard error of the mean.

The relative effectiveness of each training strategy was assessed as before with the difference score analysis. The one-way ANOVA with training as the grouping variable was significant (F (3,36) =163.5, *MSE* = 39991.89, p <0.001). This indicates training improved performance to different degrees. Post-hoc comparisons (with Tukey's HSD) confirmed that the improvement between groups was significantly different in all cases at p <0.05 (the MT vs. BT comparison was significant at p <0.01, and the comparisons between groups which used Move training, either independently or in concert with Fixate Training, and those which did not were significant at level p <0.001). This shows that with the NFC task, Fixate training, either alone or together with Move training, is effective in reducing stimulus processing time associated with the response discrimination judgement (see Fig. 2.14).

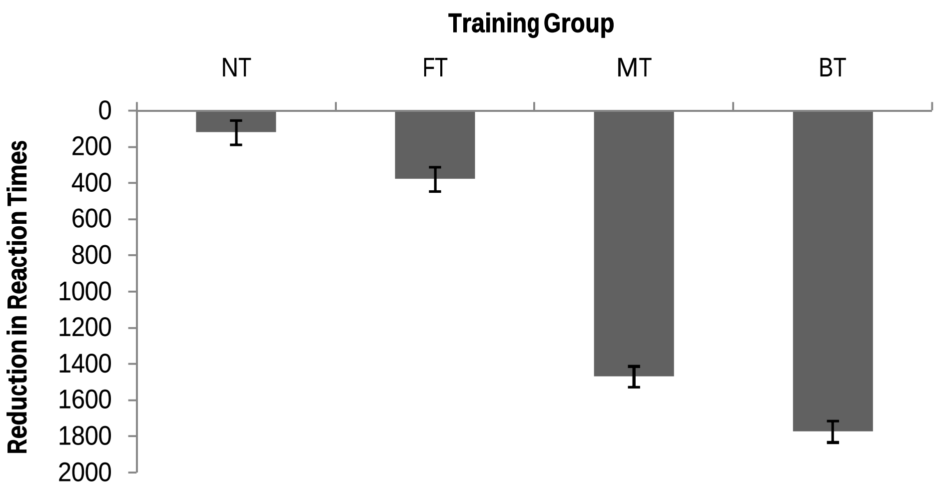

Fig. 2.14. Reaction time decrease (ms) from block 1 to block 2 for each training group. Errors bars represent standard error of the mean.

To test for comparable competence with the task on commencement of the experiment pre-training block 1 performance was checked with a one-way ANOVA. No statistically reliable differences were found (p >0.05), which is encouraging.

It was mentioned when introducing this experiment that if the prediction that NFC stimuli are harder in the grid array paradigm proves correct then, not only should a Fixate training benefit be observed, as we have seen, but also RT's relating to general performance without training should be longer in experiment 3b compared to experiment 3a. An independent samples *t*-test compared the overall mean block 1 performance in Experiment 3a to that of the current experiment. This analysis confirms the prediction (t_{99} = -9.7, p <0.001): NFC stimuli give rise to longer overall RT's without training (Exp 3a: $\bar{x}$ = 2205ms vs. Exp 3b: $\bar{x}$ = 2691ms), likely reflecting their greater general difficulty manifest in the response discrimination to feature conjunctions. This would explain the increased susceptibility to Fixate training in the present experiment.

However, because of the difference between Experiments 3a and 3b in the effectiveness of Fixate training – the advantage offered being small in both cases, and only statistically significant in the latter – one final analysis is required to confirm that Fixate training offers a genuine advantage with the NFC, but not the FCN, sub-array task. Two between-experiments comparisons were conducted, the first analysing the absolute RT scores, the second analysing the difference scores for this measure.

The same pattern of results already reported can be confirmed with reference to these statistics. First, the general linear model ANOVA with two between-groups factors (Experiment, with two levels: Exp 3a and Exp3b; and Training, with four levels: NT, FT, MT, BT) and one within-groups factor (Block, with two levels: block 1 and block 2), produced significantly different results for all comparisons (lowest F = 7.7; highest F = 1388.3; highest p = 0.006). The most important result here is that Experiment x Training x Block three-way interaction was statistically significant, as this supports the finding of differential Training efficacy depending on task. The second, univariate analysis (difference scores compared with Experiment and Training as between groups factors) mirrors these effects in the omnibus measure (all comparisons showing differences: lowest F = 8.0; highest F = 184.9; highest p = 0.006). Moreover, Tukey HSD post-hoc contrasts comparing the training groups [collapsed across experiments] revealed significant differences in every case. Crucially, the NT and FT groups differed (p =0.044), and the MT and BT groups differed (p =0.001) (the remaining comparisons were significant at p <0.001). Given that analyses confined to each of the two experiments separately did not reveal an effect of Fixate training in Experiment 3a but did in 3b, it is quite parsimonious to conclude that Fixate training has greater utility in Experiment 3b than 3a, and this is what drives the effects of Fixate training when the results of these two experiments are included in an overall analysis.

Accuracy

Contrary to Experiment 3a, when the accuracy analysis is repeated for Experiment 3b, the task is now hard enough for a training advantage to be present. A main effect of block was again found, showing the general improvement associated with practice or training (F (1,36) = 232.9, *MSE* = 35.1, p<0.001), plus a main effect of training (F (3,36) = 9.5, *MSE* = 201.0, p<0.001), highlighting the overall difference in performance percentages between groups. The NT and FT groups were markedly less accurate ($\bar{x}$ = 66.6%; $\bar{x}$ = 66.0%, respectively) than the MT and BT groups ($\bar{x}$ = 83.6%; $\bar{x}$ = 82.7%, respectively) overall. However, these effects present as a consequence of a block * training interaction (F (3,36) = 6.82, *MSE* = 35.1, p=0.001); with participants responding more accurately in block 2 depending on the training strategy(ies) they employ (see Table 2.4). (It was also noted that upon debrief no participant reported guessing any of the training contingencies).

	Block 1	Block 2
No Training	60.6	72.5
	3.1	*4.4*
Fixate Training	56.4	75.4
	5.1	*4.4*
Move Training	72.9	94.3
	2.7	*1.4*
Both Training	68.4	97.1
	3.2	*1.4*

Table 2.4. Percentage correct in block 1 and 2 for each of the training groups. Standard errors are italicised.

The interaction makes the difference score analysis likely to yield significant results. Indeed the one-way ANOVA was significant ($F(3,36) = 6.8$, $MSE = 70.2$, $p < 0.005$), and Tukeys HSD post-hoc comparisons reveal that the difference lies between the NT and BT groups ($p < 0.001$). Although the other comparisons approached significance in the direction predicted by additive training gains (see Fig. 2.15), these did not reach conventional statistical significance (α 0.05). This pattern of results suggests that training is cumulative in its effects on accuracy: the FT group must still find the target, lowering the ability to implement the Fixate strategy when they do so because available processing time has been restricted by the search; similarly, the MT group must still process the target, and because this is difficult it leads to errors. However, when the unitary benefits of each training principle are combined (i.e. with the BT group) the effects on accuracy are considerable.

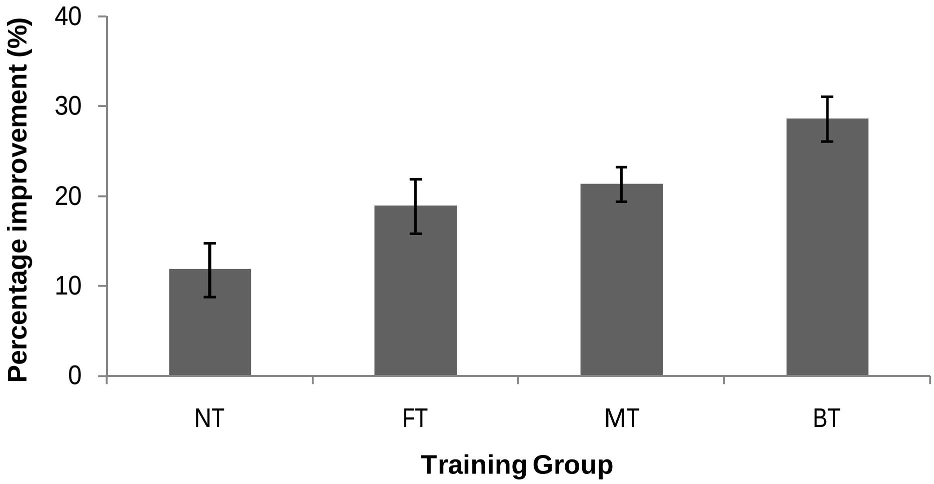

Fig. 2.15. Percentage increase from block 1 to block 2 for each training group. Errors bars represent standard error of the mean.

A final note concerns the initial accuracy scores between groups at the beginning of the experiment. Ideally these should be the same, with comparable block 1 performance. However, the one-way ANOVA conducted to test this revealed that they were not ($F (3,36) = 4.1$, *MSE* = 133.3, $p = 0.013$), and subsequent post-hocs with Tukey's HSD showed that the FT and MT groups differed at baseline, the former having worse performance ($p = 0.015$; see Table 2.4. for means). Whilst this is not desirable, it does not necessarily negate the results already reported because one of the reasons for running the difference score analysis was to control for idiosyncrasies between participants by making the effects of training (or exposure alone with the NT group) relative to each individuals' baseline performance.

2.4.3. Discussion and Chapter Conclusions

The principle reason for conducting this experiment was to see whether an advantage of Fixate training in the grid array paradigm is task dependent; specifically, whether increasing the difficulty of the stimulus discrimination judgement makes the task harder, and therefore more receptive to simplification by using a cognitive strategy which should reduce processing time. Participants searched for a uniquely defined target on the basis of the number of shapes it contained, and responded to it on the basis its feature conjunction. The feature conjunction response was believed to be more visually challenging and cognitively demanding than the response criterion used in Experiment 3a, therefore it was predicted that Fixate training would assist in the ability to carry it out, whereas no such training benefit was found in the previous study. This prediction was supported by the data. Performance gains for the response discrimination in terms of RT's were larger for the FT and BT groups than groups which were not directed in Fixate training. This demonstrates an additive training advantage, with FT improving performance over NT, MT improving over FT, and BT over MT. Moreover the advantage of training was cumulative with regard to accuracy: when Move and Fixate training were implemented in concert (i.e. with the BT group) percentage correct was substantially higher then when no training was given at all (i.e. the NT group). This was the only significant difference between groups with the accuracy data, reflecting the importance of training both systems for visual search *and* stimulus discrimination. Taken together these results demonstrate that Move and Fixate training can aid performance when exercised either independently or in concert depending on task constraints, but that the most desirable results arise when training is conjoined.

Several subsidiary predictions were also made. The first concerns task difficulty between the FCN and NFC stimuli. It was suggested that when using the visual search grid that NFC stimuli would be harder, as opposed to the single stimulus presentations of Experiment 1 where they appeared to be marginally easier possibly due to the N (number of shapes) aspect of the task being relatively straightforward when stimuli are presented alone. I suggest that the FC (feature conjunction) aspects of each task, in all of the experiments presented where FC is relevant, is more difficult than N across the board, and that this is apparent in the final experiment because the target localisation stage is (approximately) equally time consuming during visual search irrespective of the dimensions on which the target is defined. The difference score analyses, and block one performance between the present experiment and Experiment 3a, lend support to this assertion. When all participant groups are untrained at the start of the testing session NFC stimuli (Exp 3b) are considerably harder (64% correct against 83%), and give rise to significantly longer RT's (2691ms against 2205ms), than FCN stimuli (Exp 3a). Coupled with the advantage of Fixate training in Experiment 3b this reinforces the view that it is the FC aspect of the task that is responsible for the increased difficulty of the NFC stimulus set in the search-array paradigm.

With the manual response data although we can estimate portions of the trial duration allotted to visual search and stimulus discrimination, we cannot be precise with these calculations. This point relates to the above argument as well as the next prediction of Experiment 3b yet to be covered. I proposed that if feature conjunction discriminations on responding are more difficult (as they appear to be) then this might induce competition between the Move and Fixate centres at the end of a trial when participants are directed with MT independently. This could be expressed either as increased difficulty with the response discrimination (affecting accuracy), or increased difficulty with following the MT sequence (affecting the RT training effect). I also raised this as a possibility for Experiment 3a; however, at least with respect to the manual response data, it appears that neither of these outcomes occurs, irrespective of whether FCN or NFC stimuli are used. While this may be less surprising for Experiment 3a because the number categorisation on responding appears to be easier, the fact that neither of these outcomes arose in the present experiment requires further consideration. One potential reason that the difficult response task when foveating targets did not appear to conflict with the ability to carry out the MT strategy, or vice versa, is that any detriments corollary to training directed at the Move centre are hidden by the crude behavioural measures taken here. For example, maybe fixation durations or inspection times on the target are longer for the MT group, but the large reduction in RT's when MT assists with *visual search* obscures this fact.

The next chapter will evaluate the above issues by using more sophisticated and precise measuring techniques. Eye movement recordings will be taken with a similar version of Experiment 3b. This will allow task performance to be portioned into visual search and stimulus discrimination with surety, along with the ability to ascribe detailed oculomotor statistics to each of these components of the paradigm.

In conclusion I reassert that Move and Fixate training, either independently, or in concert, helps respectively with the visual search and stimulus discrimination aspects of the tasks described. It must be pointed out once more, as noted when discussing Experiment 1 (section 2.1.3), that I am aware of the fact that the way training has been defined in relation to Findlay & Walker's pathways differs somewhat from the low level characteristics of eye movement control which their model attempts to explain. However, this should not be surprising because training top down control will by nature differ from bottom up. The goal of these experiments was to relate top down control to the Move and Fixate centres using the approach described in the General Introduction (Chapter I). I believe they were successful in this objective.

3. Chapter III – Eye Tracking and Eye Movement Training in complex visual search and response discrimination.

The experiments of the previous chapter clearly demonstrate that the top down training strategies employed aid performance in the experimental paradigm used. However there is only so far one can extrapolate meaning from manual response data alone. Having established the circumstances in which Move and Fixate training benefit performance, in this chapter top down control will be addressed with respect to eye movement recordings. This will have the advantage of revealing any changes in oculomotor statistics with training which are otherwise invisible when relying solely on accuracy and reaction times. To this end a very similar version of the experimental design from the last experiment of the previous chapter (Experiment 3b) is used, because it was with this procedure that the dual benefit of Move *and* Fixate training was observed.

However, before moving on to the details of this next experiment it is worth taking the opportunity to discuss the relationship between eye tracking technology and conceptions of top down control used here and elsewhere. Yarbus (1967) provided some of the first insights into the fact that visual scanning patterns differ according to the purpose of inspection (Fig. 3.1). In this respect, top down control is variations in the allocation of overt attention based on learning which is already consolidated: we adjust the deployment of visual resources with respect to what we know about our surroundings and what we are trying to interpret from them. This is similar to the spatial priors account of Torralba et al. (2006) mentioned in Chapter I (section 1.2).

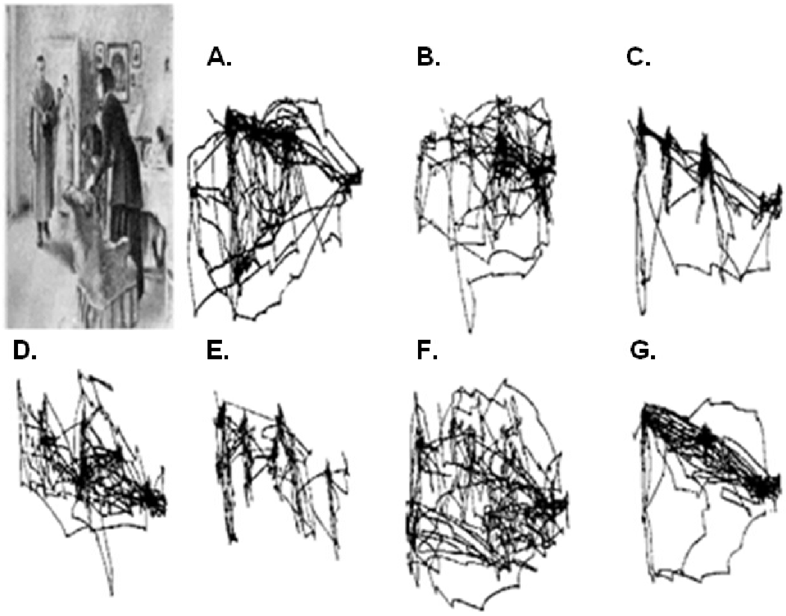

Fig. 3.1. Seven eye movement records from the same subject when viewing the picture in the top left corner ('They did not expect him by I.P. Repin). These patterns reflect different scanning on: Free examination (A); Estimation of the material status of the family depicted (B); Estimation of the ages of the people shown (C); Interpretation of what the family has been doing before the arrival of the visitor (D); Encoding of the clothes worn by each person in the picture (E); Encoding of the location of people and objects in the room (F); Estimation of how long the visitor had been away from the family (G). Adapted from Yarbus, 1967.

Much of the recent work on eye movements originates from the qualitative differences in visual scanning described by Yarbus (1967). The advancements made since have been considerable, spanning fields from biology to motor control and artificial intelligence (Duchowski, 2002, reviews eye tracking applications). We have already seen in the General Introduction of Chapter I that eye tracking technology has been used in the study of many applied areas too, and Mike Land is one of the leading scientists to bridge the gaps between disciplines with reference to modern eye movement recordings (see Land, 2006, for a review). Virtually every activity in daily living carried out by healthy human beings relies on vision, and Land amongst others (e.g. Hayhoe & Ballard, 2005) re-affirms that eye movements change according to the everyday task underway, while going a step further than Yarbus by suggesting how visual input is translated into motor output, allowing us the dexterity we enjoy through feed-forward predictive mechanisms.

I mention the above to demonstrate how the approach to top down control and eye tracking taken in this thesis differs from some previous lines of enquiry. The investigations into eye movements in everyday activities share in common the understanding of top-down control as the implementation of routines that facilitate successful completion of whatever task is being carried out, whether it be locomotion (Patla, Prentice, Rietdyk, Allard, & Martin, 1999), making a cup of tea (Land, Mennie, & Rusted, 1999), negotiating a bend when driving (Land & Lee, 1994), and many more. Top-down control in laboratory based visual search tasks which depart from 'real world' settings is likewise often thought of as the recruiting of resources necessary for the task in hand. In my tasks however, although considerable top down control of this type is necessary when untrained, the training strategies are auxiliary to this.

Therefore, *untrained* eye movement recordings with the tasks described in the previous chapter will extend the ongoing work into attentional constraints and top down control in laboratory based tasks. Additionally however, measuring the effects of Move and Fixate training on oculomotor behaviour will shed light upon voluntary and strategic influences as postulated in levels 4 and 5 of Findlay & Walker's (1999) model. (One may therefore think of the untrained group as using 'naïve' top down control, compared to the more 'focussed' top down control of the trained groups).

The way I have conceptualised training in terms of strategies for laboratory studies has close parallels with how training has previously been defined with respect to the acquisition of procedures in the real world (Kieras & Bovair, 1986). When we follow an instruction manual for example… "the initial acquisition of a procedure is a comprehension process not a skill learning process" (Ibid., 1986, p. 521). Once the method or strategy has been understood, it can be applied, thus bypassing less efficient learning when self-referencing elements of the task [which may be irrelevant to its completion in the case of my training strategies]. My tasks clearly depart from 'real world' examples of eye movements and daily activities at this stage, however, eye tracking with the visual search and stimulus discrimination paradigm in a laboratory environment allows the degree of control necessary to properly understand oculomotor parameters and how they change as a function of training.

Measuring eye movements: A brief overview

The first objective measurements of eye movements began around the start of the twentieth century (see Delabarre, 1898), but the devices used often provided only crude approximations of eye position. As methods advanced the norm became to photograph movements of a light source reflected off the cornea, a technique first introduced by Dodge & Cline (1901), the basic principles of which still apply today. Modern eye tracking equipment commonly uses infra-red light to illuminate the pupil (the 'dark pupil' method) and give a corneal reflection (CR); the pupil position or the corneal reflection can then be captured with high-speed video cameras recording usually at at least 50Hz frequency (although the most advanced hardware can now record as fast as 1000Hz).

Other systems have also been developed; some which track an outline of the iris (Land, 2006); others which use a coil annulus, like a contact lens, which is placed on the surface of the eye and its magnetic field displacement is measured as the eye rotates in its orbit (Robinson, 1963). The electrooculograph (EOG) is yet another technique. Here, electrodes are placed near the eye and measurements are based on the principle that the cornea has a positive electrical potential compared to the retina; when the eye moves however this resting potential changes with respect to the reference electrode (see Woestenburg, Verbaten, & Slangen, 1984). The method of choice depends on what you are studying, but as a general rule the use of coils and EOG is reserved for investigations which are more physiological in emphasis. Tracking the pupil or corneal reflection with infrared is most commonplace in studies of visual cognition, the theme we are most concerned with in this thesis.

The set-up of infrared eye trackers differs, some are desk-mounted, and therefore require a chin rest (or bite bar depending on the degree of precision required) because the recording coordinates are eye- , not head-, centred. Others are head-mounted, or able to incorporate a head-centred reference frame, which allows recordings to be taken for tasks which are more natural than static viewing.
A calibration procedure is necessary before recording can commence to establish where the observer is looking relative to the recording equipment. Typically this involves fixating a series of dots presented on a monitor which appear at locations chosen to represent the dimensions of the screen. Once a good calibration has been obtained it is then possible to determine the point of regard anywhere in the viewing plane.

The faster the sampling rate the larger the amount of raw data collected. Commonly some algorithm is used to parse this source data into events: saccades, fixations, and blinks. Each event will have parameters set for its definition based on thresholds for factors such as dispersion (for fixations), velocity and acceleration (for saccades), and lack of signal (for blinks). The start and end point of each event can be time-stamped along with its position in *xy* coordinates (objective recording in 3-dimensions is much more complex; one has to use predefined *z* planes and vergence measures from binocular viewing).

Once one has a manageable data set, split into the different types of oculomotor behaviour of interest, one then needs to relate this data to the experimental design in hand. Typically the viewing plane is split into interest areas; when stimuli are presented on a monitor this usually involves dividing the screen into important regions using pixel coordinates; the boundaries of interest areas can also be set with reference to horizontal and vertical visual angles however. Once we know exactly where a person is looking from the beginning to the end of a recording period based on interest areas, a multitude of results can now be gleaned from the data set, both within and across subjects: mean fixation duration, number of fixations, probability of re-fixating certain interest areas, saccade amplitude, and a vast amount more! Depending on the experimental design these data can be collapsed across observers and conditions, and subjected to statistical analysis in the same way as any other dependent variable.

Having reviewed eye tracking applications in the context of top down control, and how eye movement data is collected and subsequently treated, I will now turn to the next experiment of this thesis, which draws upon this background.

3.1. Experiment 4 - Eye movements and Move training combined with Fixate training.

While the results of Experiment 3b are promising in showing that when stimulus processing demands are high both Move *and* Fixate training can be beneficial, they do not provide any objective assessment of the effects of training on eye movements. In particular, I have suggested on several occasions now that when processing demands at fixation are high and participants are only directed in MT, the urge to move the eyes to the next location predicted by the training sequence may hinder the ability to complete the task at fixation. In Experiment 3b, because the MT group have no strategy to help them with the response discrimination judgement, maybe activation induced in the Move centre when following the pattern of target presentation competes with activation induced in the Fixate centre by the difficult response discrimination judgement at the end of a trial. Although no detriments pointing to the occurrence of such competitive interactions were identified in Experiment 3a or 3b, this might be because the dependent measures were not sensitive enough. Perhaps Move training alone *does* effect target processing time at the end of a trial, but this is obscured in the reaction time measure by the fact that following the predictable sequence of target presentation dramatically reduces visual search times. Eye movements were recorded in a very similar version of Experiment 3b to help shed light on this issue. This task was chosen because it was with the NFC stimuli used in this experiment that an additive advantage of Move *and* Fixate training was found, and this adds to the argument that responding according to feature conjunction is hardest, therefore most likely to exacerbate competition between the Move and Fixate centres as described.

It was suggested in the last chapter that competition between the Move and Fixate centres may be expressed in different ways. This is addressed more specifically here with small change to the design of Experiment 3b for use in Experiment 4. Whereas previously there were two trial blocks of equal length, in the present experiment block 2 was divided in two: half of its trials were the same as before, but in the other half the availability of feedback was altered. Instead of a red (incorrect) or blue (correct) transient mask being displayed at the end of each trial, a faint grey mask was always presented irrespective of whether the trial was correctly responded to. Other than one half of block 2 the presentation of feedback was kept the same as in Experiment 3b. The rationale for this manipulation was to try and distinguish between *reduced* or *increased* target processing times due to Move centre activation, and is explained below.

Post-error slowing is an established effect showing an increase in response latencies immediately following awareness of a mistake (Bogte, Flamma, van der Meere, & van Engeland, 2007; Polli et al., 2006; Rabbitt, 1966). This increase in the time taken to respond following an error is associated with higher accuracy, implying a trade-off whereby slowing down on the trial following an error leads to a higher probability of answering that trial correctly. Removing feedback therefore effectively means this external error monitoring process must be internalised, which for the difficult task described is probably less reliable than veridical computer generated feedback. Without an external anchor reinforcing the need to respond correctly, MT participants may be more entrenched in following the sequence of target presentation from trial-to-trial, and less concerned with carrying out the response discrimination accurately. If so, the balance of activation at the end of a trial may be biased in favour of the Move centre. When feedback is removed therefore one would expect an accuracy decrease to be associated with a reduction in target processing time for the MT group alone.

Alternatively, it is possible that when feedback is available anxiety about responding correctly is heightened, to the detriment of the MT group. It has been reported that efficiency at difficult visual search improves when participants are instructed to relax, surrendering slow executive control processes to more efficient and automatic passive processes (Smilek, Enns, Eastwood, & Merikle, 2006). Given that we are able to self-regulate error monitoring without external feedback (Holroyd, Hajcak, & Larsen, 2006), perhaps feedback is unhelpful, only increasing anxiety with such a taxing paradigm. This could detract from the ability to carry out the task (as Smilek et al. suggest) and may be expressed as an extension of target processing time prior to responding in the MT group. This would be the flip-side of the competitive relationship between the Move and Fixate centres at the end of a trial: while concentrating efforts on completing the stimulus discrimination response correctly, the 'pull' of the Move centre may encumber processing resources sub-served by the Fixate centre, thereby lengthening the time normally needed to foveate the sub-array target in order to discern the correct response.

Another modification in Experiment 4 is that the FT group was dropped from the design. Given that FT independently has been seen to assist stimulus discrimination performance in two previous experiments in this thesis (Exp 1 & Exp 3b), and that these results concur with other observations of reduced processing difficulty at fixation even when stimulus properties are unchanged (Gould, 1973; Zingale & Kowler, 1987), the inclusion of an FT group was viewed as unnecessary. The goal of the research described in this thesis is to elucidate how eye movement training can *improve* performance in visual tasks compared to earlier attempts. Training people where to look (i.e. MT) is most intuitive and has been suggested by others (e.g. Coyne, 1997). As we have seen this gives rise to large improvements in search times, but may however be further supported if combined with a strategy for reducing processing load (i.e. BT). When directed in FT independently on the other hand the large reductions in visual search times associated with MT obviously do not occur. Since we are concerned with the conditions which lead to the *best* performance and with how to subvert potential negative consequences arising due to Move—Fixate competition, the FT group was not included because FT alone does not produce large gains for the visual search aspect of the task. Therefore only three participant groups contributed to the data collected in Experiment 4: NT, MT, and BT (pragmatically, this also reduces the time taken to collect data for what is already a very lengthy experiment in terms of subject numbers).

The predictions above notwithstanding, I expect to replicate the manual response data from experiment 3b; these results should also be reflected in the oculomotor statistics. Moreover it is predicted that BT will bring about the best performance, not only in terms of accuracy and reaction times, but also in terms of identifiable eye movement characteristics.

3.1.1. Method

The methodology of Experiment 4 was essentially the same as Experiment 3b with the addition of eye movement measures. The only notable changes to the design were that feedback availability was manipulated as an independent variable, and that the FT group was omitted. The details of these adjustments and any other minor differences are given below, but the reader is referred to Chapter II for specifics of the general method because this information is not repeated here.

Participants

Forty eight naïve paid participants (40 female) were recruited from the University of Nottingham's student population and surrounding local area (mean age 21yrs, range 18-30). All participants reported normal or corrected-to-normal vision.

Stimuli and Apparatus

The same NFC sub-arrays were presented in the 3x3 search-array as in Experiment 3b. Stimuli were displayed on a 19" Samsung SyncMaster LCD monitor, running at 1024 x 768 pixel resolution. The smaller screen size meant that stimuli were slightly reduced in size compared to the previous version of this experiment. The search-array now subtended 24x24° visual angle, and therefore each sub-array subtended 8x8°. A PC operating with a Pentium 3 processor was used to run the experiment via E-prime software as before. A host PC, with the same specifications, was used to operate the eye tracker using iView software.

A desk-mounted Red-Eye III eye tracker (Sensory Motoric Instruments) was used to record eye movements of the right eye at 50hz (using the dark pupil method). Fixations were defined as periods of ocular stability in between saccades with a minimum duration of 80 milliseconds (apart from this the manufacturers default specifications were used to parse the sample data).The eye tracker was linked to software with the capability to create a text file for each participant, containing important session events such as trial number, fixation duration, *x* and *y* pixel coordinates of eye position, saccade amplitude etc. These data were recorded, and collated offline with in-house programming routines in Microsoft Excel.

The layout of the search-array, along with the uniform order of target presentation, lends itself to the specification of regions of interest for eye tracking analysis. If a fixation occurred within the *xy* coordinate bounds for the sector of the search-array containing the target it was flagged. It was then possible to compute several measures of overall visual search performance and target processing time. These are outlined in full in the design section below.

Design

As previously, the experiment was divided into two blocks of 128 trials, the first serving as a baseline. Training was again provided, as before, in between blocks 1 and 2 depending on which of three groups the participant was randomly allocated to (NT: N = 17; MT: N = 15; BT: N = 16). The respective training strategies for each group were to be used in the second block of trials.

The additional independent variable incorporated into the design of Experiment 4 will be referred to as Feedback. This was a within groups factor, with half of block 2 containing feedback (FB) and half not (NFB). The order of this manipulation was counterbalanced across subjects. Throughout Block 1, and the 64 FB trials of block 2, feedback was always given as before, by way of a red (incorrect) or blue (correct) transient screen after each trial ('time-outs' were considered incorrect). In the 64 NFB trials of block 2 the blue or red mask was replaced with a grey mask in all instances, such that feedback was no longer available. Within each block, trial selection and stimulus presentation was determined in the same way as Experiment 3b.

Several dependent variables contributed to the measures taken from this design. As before, behavioural data was collected: manual reaction times and accuracy. A number of measures were drawn from the eye movement recordings also. General visual search performance was assessed with reference to the average number of fixations per trial and the average time to first target fixation. As the focus of this experiment is the effect of training on target processing, several measures of eye movements pertaining specifically to the target were also taken: the mean fixation duration on the target, the mean gaze duration on the target (defined as the cumulation of fixation durations for successive fixations on the target; one 'gaze' amounting to the summed time of fixations in a run within the target's interest area in the grid), and the average number of fixations made on the target. As Findlay & Walker's (1999) model focuses primarily on individual fixation durations, the a priori predictions concern mean fixation duration on the target. However, as it is likely that more than one fixation on the target will be necessary to determine the correct response, it is possible that any effects of training will be borne out in the collective measures of target processing (e.g. gaze durations).

For purposes of analysis the data collected will be treated in terms of changes in block two relative to baseline (the difference score measure previously employed), although the absolute means in each condition are also given. I chose to use this method of analysis exclusively here, and henceforth, because it provides the same information as when comparing the absolute values, but the statistics are more powerful and representative of individual changes in performance between blocks 1 and 2. Therefore, for each participant, the mean of a dependent variable at baseline (i.e. block 1) was subtracted from its mean in both the FB and NFB portions of block 2.

Procedure

The procedure was identical to Experiment 3b with the addition of a calibration procedure (using iCal) for the eye tracker before the practice blocks. Calibration involved fixating a series of nine dots presented serially at each corner of the screen, the centre of each outside edge of the screen, as well as one in the middle of the screen. This procedure was repeated if necessary, and the importance of keeping absolutely still in the chin rest was stressed to participants.

3.1.2. Results

Reaction Times

Reaction Times (RT's) were extracted from the data set for each of the two experimental blocks across all three training conditions. A tiny amount of responses (0.52%) were anticipatory (RT <200ms) and thus were removed. Only correct responses were included for subsequent RT analysis (23% of the remaining data set were incorrect). See Table 3.1 for overall means.

Difference scores for RT's were analysed by way of a 3x2 mixed factorial ANOVA with three levels of Training and two levels of Feedback. A significant main effect of training was observed ($F(2, 45) = 138.1$, *MSE* = 153861.3, $p<0.001$) which reflects the MT group's greater reduction in RT over the NT group, and the BT group's greater reduction over the MT group (NT: $\overline{x_{Block_2} - x_{Block_1}}$ = -158ms, S.E.M = 67.3; MT: $\overline{x_{Block_2} - x_{Block_1}}$ = -1238ms, S.E.M = 71.6; BT: $\overline{x_{Block_2} - x_{Block_1}}$ = -1722ms, S.E.M = 69.3). Tukey's HSD post-hoc comparisons confirmed these differences, with each groups' reaction time decrease differing significantly from the other groups' (all p's <0.001). This replicates the RT results from Experiment 3b, as expected. There was no main effect of feedback neither did feedback interact with training.

As the trained groups have prior knowledge about where the target will occur in the next trial it could be argued that they have an unfair advantage in the above comparisons because they could move their eyes to the upcoming target location in the inter-trial feedback interval of 200ms, whereas the NT group must commence their search for the target when the next trial begins. To account for this, 200ms was subtracted from the training effect of the trained groups and the analysis was repeated. This made no difference to the results or the significance levels reported; training remained additive in its effects.

Finally, baseline RT's were compared with a one-way ANOVA to test for comparable performance at baseline. No differences were observed (p = 0.51), suggesting no group were any faster at carrying out the task successfully at the beginning of the experiment (see block 1 baselines in Table 3.1).

	Block 1 (baseline)	Block 2	
		Feedback	No Feedback
No Training	2722 *45.7*	2536 *57.5*	2592 *50.5*
Move Training	2721 *36.2*	1499 *100.7*	1465.3 *82.6*
Both Training	2658 *48.5*	892 *39.1*	980 *54.6*

Table 3.1. Mean reaction times (ms) for each training group across conditions. Standard errors are italicised.

Accuracy

Percentage correct was analyzed in the same way as RT (see Table 3.2 for overall means in each condition). Again a main effect of Training was observed (F (2, 45) = 10.0, *MSE* = 205.2, p<0.001), illustrating differential improvements in accuracy between groups. The between groups effect was examined with Tukey's HSD post-hoc comparisons which revealed the greater improvement of the MT group compared to the NT group ($\overline{x_{Block_2} - x_{Block_1}}$ = 26.4%, S.E.M = 2.6; $\overline{x_{Block_2} - x_{Block_1}}$ = 16.4%, S.E.M = 2.5; respectively, p = 0.021), and the greater improvement of the BT group ($\overline{x_{Block_2} - x_{Block_1}}$ = 32%, S.E.M = 2.5) compared to the NT group (p<0.001). The MT and BT groups did not differ (p = 0.289). There was no main effect of feedback, neither was the interaction significant.

Accuracy scores at baseline (see Table 3.2) were compared in a one-way ANOVA to check for comparable performance before training. This analysis was significant (F (2, 45) = 5.6, *MSE* = 132.5, p = 0.007), highlighting that the baseline performance of the NT group was worse than that of the MT or BT groups (Tukey's HSD p's <0.05 in each case); the MT and BT groups did not differ at baseline (p = 0.963). Whilst slightly different abilities between groups at baseline was not desired, it does not detract from the pattern of results presented because the purpose of calculating the relative change data was to assess individual difference in performance, accounting for variability between people.

	Block 1 (baseline)	Block 2	
		Feedback	No Feedback
No training	52.6	71.1	66.9
	3.3	*2.7*	*3.6*
Move training	63.6	88.5	91.5
	1.4	*2.9*	*1.6*
Both training	64.7	98.0	95.2
	3.3	*0.5*	*2.9*

Table 3.2. Mean percentage correct for each training group across conditions. Standard errors are italicised

Eye Movement Recordings

To properly understand the behavioural data obtained in the context of eye movement control it is necessary to examine certain statistics of visual search and target processing performance. Thus far training, even if directed at the Move centre in isolation, appears to be beneficial, both in its effects on RT and accuracy. However, it is not so surprising that when faced with a difficult visual search task, advice about where to move the eyes to find the target facilitates reaction times. What is more interesting is the effect of training on processing the target once fixated. Is the time spent fixating the target extended or reduced as a result of MT, and how does this fit with the behavioural data presented thus far? Moreover, does combined Move and Fixate training (i.e. BT) reduce the time spent fixating the target for correct stimulus discrimination responses?

Several measures of target processing address the above questions; firstly however, visual search performance is qualified with respect to eye movement recordings. As with the manual response data, relative change in the eye movement measures between block 1 and block 2 was calculated (although the absolute values are also given in Tables 3.3 – 3.7). Because there were no statistical differences between the groups' baseline data for any of the eye movement measures, details of these comparisons are omitted.

A number of pre-analysis filters were imposed upon the eye measures taken: as with the manual response data anticipatory responses (RT <200ms) were removed, as well as incorrect trials. Of the remaining trials only those in which the target was fixated were analysed. If a participant had less than 10 trials contributing to their cell mean in block 1, or the FB or NFB portions of block 2 they were removed from the subsequent eye movement analysis. Loss of calibration among certain participants meant that nine were excluded due to this criterion, 2 from the NT group, 3 from the MT group and 4 from the BT group. An additional participant was also removed, from the MT group, owing to tracker loss. Following these exclusion an average 45 trials contributed to participants' cell means for the eye movement measures taken.

Overall visual search performance

The average number of fixations per trial gives an indication of search efficiency (overall means in Table 3.3). The difference score analysis for this measure revealed a main effect of training: $F(2, 35) = 14.9$, *MSE* = 7.3, $p<0.001$, highlighting that both of the trained groups make less fixations in the second block than the untrained group (NT: $\overline{x_{Block_2} - x_{Block_1}}$ = -0.84, S.E.M = 0.49; MT: $\overline{x_{Block_2} - x_{Block_1}}$ = -4.04, S.E.M = 0.58; BT: $\overline{x_{Block_2} - x_{Block_1}}$ = -4.49, S.E.M = 0.55; Tukey $p<0.001$ when each trained group is compared to the untrained group).The MT and BT groups did not differ, showing comparable reductions in the average number of fixations made per trial following training (p = 0.841). This effect maps onto the RT data, the reduction in RT due to training paralleling fewer fixations within a trial.

There was no main effect of feedback, but feedback did interact significantly with training (F (2, 35) = 3.9, *MSE* = 0.3, p = 0.029; see Fig. 3.2). Paired-samples t-tests comparing the reduction in number of fixations across feedback conditions within groups revealed a trend that the MT group have a slightly bigger reduction when feedback is not provided ($\overline{x_{Block\,2_{FB}} - x_{Block\,1}}$ = -3.78; $\overline{x_{Block\,2_{NFB}} - x_{Block\,1}}$ = -4.30; t_{10} = 2.01, p = 0.072). The within groups comparisons for the NT and BT groups did not approach significance (p = 0.199; p = 0.23, respectively).

	Block 1 (baseline)	Block 2	
		Feedback	**No Feedback**
No Training	7.46	6.45	6.79
	0.26	*0.43*	*0.42*
Move Training	7.47	3.69	3.17
	0.38	*0.37*	*0.25*
Both Training	6.72	2.17	2.28
	0.67	*0.10*	*0.13*

Table 3.3. Mean number of fixations per trial for each training group across conditions. Standard errors are italicised

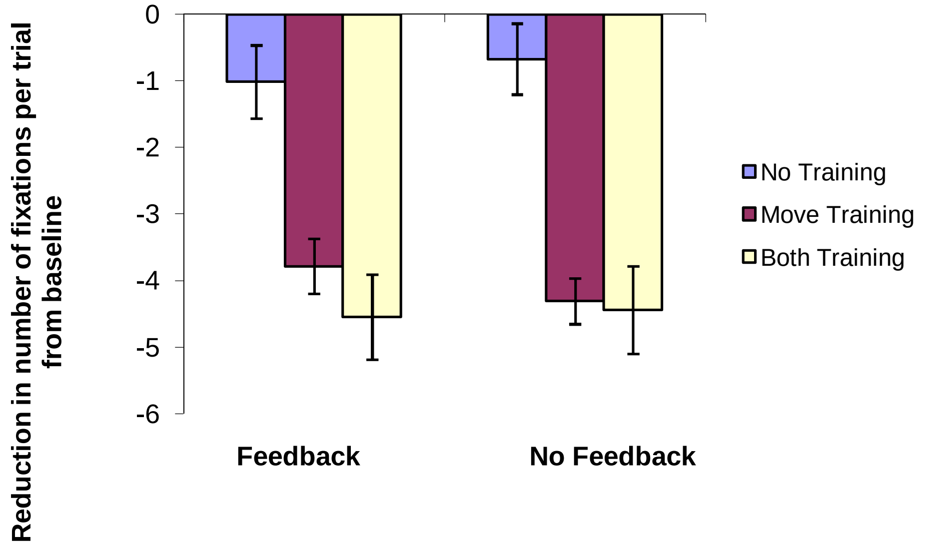

Fig. 3.2. Reduction from baseline in the mean number of fixations per trial for each group, across feedback conditions. Error bars represent standard error of the mean.

The time from commencement of a trial to fixation of the target also gives an indication of search efficiency (overall means in Table 3.4). The difference score analysis for this measure revealed a significant main effect of training only (F (2, 35) = 76.9, *MSE* = 146175.7, p<0.001), there was no main effect of feedback, neither did feedback interact with training. Post-hoc comparisons demonstrated that both of the trained groups differed significantly from the untrained group (NT: $\overline{x_{Block_2} - x_{Block_1}}$ = -57ms, S.E.M = 69.8; MT: $\overline{x_{Block_2} - x_{Block_1}}$ = -1006ms, S.E.M = 81.5; BT: $\overline{x_{Block_2} - x_{Block_1}}$ = -1278ms, S.E.M = 78.0; Tukey, p<0.001 in each case). The MT and BT groups, although tending towards a greater reduction in search time for the latter, did not quite differ statistically (p = 0.053). This pattern of results again complements the RT analysis, demonstrating the improved search efficiency of the trained groups.

	Block 1 (baseline)	Block 2	
		Feedback	No Feedback
No Training	1380	1291	1355
	64.2	*58.5*	*46.2*
Move Training	1392	439	332
	37.8	*104.4*	*71.1*
Both Training	1480	185	218
	83.3	*21.2*	*17.1*

Table 3.4. Mean time to first target fixation (ms) for each training group across conditions. Standard errors are italicised.

Target processing performance

To ascertain whether MT alone affects the time spent processing the target in order to make a correct response, mean fixation durations on the target were calculated (overall means in Table 3.5). There were no effects with the difference analysis however, despite the fact that the direction of the means suggests a slight trend for the trained groups to have longer fixations on the target following training (NT: $\overline{x_{Block_2} - x_{Block_1}}$ = -0.6ms, S.E.M = 18.42; MT: $\overline{x_{Block_2} - x_{Block_1}}$ = 47.5ms, S.E.M = 21.5; BT: $\overline{x_{Block_2} - x_{Block_1}}$ = 51.2ms, S.E.M = 20.6).

	Block 1 (baseline)	Block 2	
		Feedback	No Feedback
No Training	355.8	348.0	362.3
	19.6	*20.6*	*24.4*
Move Training	376.5	415.7	432.2
	25.5	*31.1*	*32.4*
Both Training	305.8	358.0	356.2
	24.9	*16.5*	*22.5*

Table 3.5. Mean target fixation duration for each training group across conditions. Standard errors are italicised

It was posited in the penultimate paragraph of the design section above that any affects on target processing performance may be borne out in collective measures of target processing, rather than individual fixation durations per se, because it is highly likely that more than one fixation on the target will be required to make the correct response. Gaze durations offer the most direct assessment of this because a single 'gaze' was counted as the summation of fixation durations for consecutive fixations on the target. This provides a measure therefore of how long the target is scrutinized on a single inspection (see Table 3.6 for overall mean gaze durations). The difference score analysis for this measure revealed a main effect of training (F (2,35) = 3.5, *MSE* = 86124.9, p <0.05), reflecting the MT group's increase in gaze durations on the target ($\overline{x_{Block_2} - x_{Block_1}}$ = 149.3ms, S.E.M = 62.6) relative to the NT and BT group's ($\overline{x_{Block_2} - x_{Block_1}}$ = -63.9ms, S.E.M = 53.6; $\overline{x_{Block_2} - x_{Block_1}}$ = -12.0ms, S.E.M = 59.9, respectively). There was no main effect of feedback, and no interaction. Tukey post-hoc comparisons assessing the between group's effect revealed a significant difference between the NT and MT groups (p = 0.036), and importantly, although the BT group were also directed with training aimed at the Move centre, their gaze durations did not increase and did not differ from the NT group's (p = 0.796). This suggests that the use of training directed at the Fixate centre offsets the longer processing time seen in the MT group. While a significant difference between the MT and BT groups was desirable this effect failed to reach significance (p = 0.165). However, it will be seen that with the number of fixations on the target (covered next) that the BT group make significantly less fixations following training.

	Block 1 (baseline)	Block 2	
		Feedback	No Feedback
No Training	645.5	566.2	597.0
	35.9	*43.4*	*39.0*
Move Training	698.2	837.3	857.6
	53.5	*71.5*	*90.6*
Both Training	566.1	537.3	570.8
	55.7	*31.7*	*44.7*

Table 3.6. Mean gaze durations for each training group across conditions. Standard errors are italicised

Finally, the last measure of target processing taken was the number of fixations on the target per trial (overall means, Table 3.7). The difference score analysis for this measure revealed a significant main effect of training only (F (2,35) = 4.0, *MSE* = 0.3, p = 0.026); there was no main effect of feedback, neither was the interaction significant. Tukey post-hoc comparisons revealed that this effect is driven by the difference between the MT and BT groups, with the former on average making roughly the same amount of fixations on the target after training ($\overline{x_{Block_2} - x_{Block_1}}$ = -0.06, S.E.M = 0.1)and the latter making less ($\overline{x_{Block_2} - x_{Block_1}}$ = -0.52, S.E.M = 0.1, p = 0.02). The NT group ($\overline{x_{Block_2} - x_{Block_1}}$ = -0.29, S.E.M = 0.1) did not differ from either the MT group or the BT (p’s = 0. 297 and 0.295, respectively). While this effect deals with small numbers, the difference observed here reflects that although the BT groups’ gaze durations following training did not differ significantly from the MT groups’ (despite the fact that this was the direction of the results), the number of fixations they made on the target following combined training did decrease significantly. These results suggest that Move and Fixate training in concert leads to more efficient target processing than Move training alone.

	Block 1 (baseline)	Block 2	
		Feedback	No Feedback
No Training	2.4	2.0	2.1
	0.1	*0.1*	*0.1*
Move Training	2.3	2.3	2.2
	0.1	*0.2*	*0.1*
Both Training	2.2	1.6	1.7
	0.1	*0.1*	*0.1*

Table 3.7. Mean number of target fixations per trial for each training group across conditions. Standard errors are italicised

3.1.3. Discussion and Chapter Conclusions

Several predictions were made about the effects of training on eye movement characteristics. Those relating to the feedback manipulation are addressed first, before moving on to the overall pattern of results as they relate to each training group.

It was hypothesised that manipulating feedback would give rise to either a decrease in target processing time for the MT group (when feedback was not available) or a increase (when feedback was available). The first prediction was attached to the idea that in the absence of feedback participants would become more entrenched in following the predictable sequence of target presentation, and that as a result the reciprocal relationship between the Move and Fixate centres would lead to the target being inspected for insufficient time. An accuracy decrease was therefore proposed in connection with this potential outcome. The second prediction was based on the argument that providing feedback would increase stress about responding correctly; the reciprocal relationship between the Move and Fixate centres could therefore lead to the opposite outcome: an increase in target processing time. While this second possibility may also be thought to decrease accuracy, because no accuracy decrement was found in the previous version of this experiment when feedback was available (Exp 3b), an accuracy decrease was not linked to this prediction.

The latter account was supported in part by the data, with the MT group showing increased target processing time (revealed in the gaze duration measure). However, the effect was not feedback specific, occurring irrespective of whether feedback was presented or not. As such, there was no evidence for a reduction in target processing time, and associated decrease in accuracy in the MT group. On the surface therefore it appears that MT does increase target processing time and that the feedback manipulation was unnecessary to reveal this effect. (Although note that feedback was not entirely insignificant in affecting oculomotor behaviour: there was a marginal improvement for the MT group in terms of fewer fixations per trial when feedback was withdrawn, perhaps indicating greater adherence to the training sequence as suggested).

Not only does the MT group show an increase in target processing time at the end of a trial, possibly due to competition between completing the response discrimination and suppression of the next eye movement in the sequence, but the BT group, despite utilising the same training sequence of target presentation, do not show such an increase. Conjoined training seems to offset the artificial extension in the time needed to distinguish the correct response once focussed on the target, seen when directed with MT in isolation. This result, combined with the overall pattern in the eye movement and manual response data, suggests that performance is best when training is directed at *both* the Move *and* Fixate centres.

As individual fixation durations on the target were not significantly different between groups (revealed in the mean target fixation duration measure) one must conclude that the acquisition of information from each target fixation of the MT group is less than optimal, a drawback remedied by providing Fixate training in concert with Move training. The BT group require fewer fixations (of comparable duration to the MT group) to process the target fully. This is not to say that the BT group apprehend the same information as the MT group with greater economy (the target's colour and shape are irrelevant to the BT group); only that attention to redundant detail is removed by the provision of Fixate training. Although Findlay & Walker's (1999) framework primarily deals with single fixations, the present results suggest that when the task relies so heavily on top down control, effects on the processing efficiency of each fixation may be evident only in aggregated oculomotor statistics not individual fixation durations per se.

I mentioned at the beginning of this chapter that incorporating eye tracking into the present paradigm would also shed light on more classical conceptions of top down control (i.e. performing the task when *untrained* –naïve to the training contingencies –still depends considerably on high level cognitive influences). Our understanding of visual search and feature integration originates from a literature which draws heavily on notions of covert attention, but less so on eye movements; so called "overt attention" (Duncan & Humphreys, 1989; Quinlan, 2003; Shen & Pare, 2006; Treisman & Gormican, 1988; though it is noted that big steps have been made to bridge this gap in recent years e.g. C. C. Williams & Pollatsek, 2007; D. E. Williams, Reingold, Moscovitch, & Behrmann, 1997). The eye movement data from the present study add to the advancements being made in understanding how attention translates into eye movements in visual search, revealing that, despite the difficulty of the task, participants can still move their eyes to the target then interpret the response relatively quickly, even when they are unaware of the training strategies (it is noted that upon debrief none of the participants spontaneously noticed any of the training contingencies). Moreover, performance *improved* in the NT group despite the fact they were given no strategic advice: their overall visual search performance improved marginally, but also their ability to carry out the response discrimination became much better as the experiment progressed – gaze durations on the target actually decreased. This indicates that, despite the time pressure imposed (each trial = 4000ms, maximum), the NT group learn to classify the feature conjunction response criterions more resourcefully. Indeed, upon debrief, some participants from the NT group expressed that they developed their own strategies to help them respond correctly. For example, they may remember certain sub-array configurations and the appropriate response.

The apparent improvement of the NT group with the response discrimination leads on to another point concerning the extended gaze durations of the MT group; do the increased gaze durations seen when training is directed at the Move centre in isolation really reflect a competitive interaction between processing the target and making the next eye movement in the sequence? Perhaps the explanation is less esoteric: the NT group have a smaller portion of the trial remaining once they have located the target, by virtue of necessity therefore they learn to interpret the response more efficiently; conversely, because the visual search requirement is effectively removed for the MT group, they might spend the remainder of the trial trying to work out the correct response, and do not improve with this aspect of the task because the available time is not constricted. This argument detracts from the proposal above that the MT group's increased gaze durations are due to reciprocal antagonism between the Move and Fixate centres. It is worth reiterating however that whatever the reason for the apparent extension in target processing time seen in the MT group, this effect is eliminated when directed in *both* Move *and* Fixate training (i.e. as evidenced by the BT group).

If, in the interest of parsimony, one favours the alternative reason for the MT group's increased target processing time, should we accept that when training is directed solely at the Move centre it does not hinder information processing sub-served by the Fixate centre? On the basis of this evidence alone we should not. A plausible reason it was difficult to find solid evidence of competitive inhibition between the Move and Fixate centres in Experiment 4 is because such competition is less likely to arise unless the next eye movement in the MT sequence competes with target processing *within the same trial.* With the present paradigm participants do not need to move their eyes to the next target location until the trial is over, therefore lessening the source of conflict between target processing and eye movement execution (sub-served by the Move and Fixate centres respectively). The next series of experiments will address this issue, placing spatially separated items in a visual array in direct conflict intra-, rather than inter-, trial.

4. Chapter IV – Can Move Training be detrimental to performance?

The first experiment of this chapter (Experiment 5) has been accepted for publication in the journal *Perception*: Dewhurst, R., & Crundall, D. (2008). Training eye movements: Can training people where to look hinder the processing of fixated objects? *Perception 37,* 1729-1744.

Is eye movement training always helpful, or can it actually make people worse? Although we have tentative evidence that training directed at the Move centre alone can lessen the efficiency of fixations (from Experiment 4 in the previous chapter), it remains unclear whether this is due to the reciprocal relationship between the Move and Fixate centres. The series of experiments presented in this chapter will tackle this issue more directly, using visual arrays in which stimuli compete for attention *within the same trial*. The logic behind this adjustment is that if Move training directs attention away from a task-relevant item towards another area in the periphery, the processing of that item will be hindered in some way. This draws on the same argument I have previously outlined; namely, that the urge to make an eye movement (subserved by the Move centre) will hinder the processing of fixated objects (subserved by the Fixate centre), owing to the competitive relationship between saccades and fixations in Findlay & Walker's model (1999). However, the difference in methodology employed in this chapter may be necessary to bring about this effect –perhaps competition between the Move and Fixate centres only gives rise to the kind of performance detriment described when Move training causes conflict between items which are present simultaneously. This would also more closely resemble naturalistic viewing, where sources of potential competition between the Move and Fixate centres are not segregated into artificial temporal intervals, as was the case in the previous experiments described.

Before outlining the particulars of the experiments covered in this chapter, it is worth spending some time to review research on conflict between top down intentions and bottom up signals. How does this fit with the contention suggested above? Is there evidence which could be explained with reference to Move–Fixate competition? Could previous attempts to train eye-movements benefit from placing emphasis on information acquisition at fixation, *as well as* attempting to improve performance through promoting vigilant visual scanning?

As was remarked upon in Chapter I, there has been relatively little research directly addressing the topmost levels of Findlay & Walker's (1999) model. But there has been some. Mosimann, Felblinger, Colloby, & Muri (2004) assessed the influence of different types of instruction on saccadic eye movement control. Using pro-, and anti-, saccade tasks participants were instructed to either purposefully withhold saccade triggering, deliberately make inaccurate saccades, or to quickly re-direct saccades after fixating a saccade target. Perhaps not surprisingly, the instruction to 'delay' increased initial saccade latency (the fixation duration immediately prior to a stimulus elicited saccade); however, it also affected saccadic accuracy, leading to undershoots in localising pro-saccade targets. The instruction to deliberately make inaccurate saccades similarly increased saccade latency. In accordance with task requirements in this condition participants' saccades were also inaccurate, but this time in the opposite direction: saccade landing points were inclined to overshoot the actual target location. The instruction to fixate a pro-saccade target then quickly look away was included for comparison with anti-saccade errors (i.e. when participants are supposed to look in the opposite direction to an abrupt target onset, but instead are drawn towards it). This instruction to immediately re-direct stimulus driven eye movements gave rise to longer inter saccadic intervals (ISI's) prior to the re-directed saccade than those observed when erroneous anti-saccades are corrected.

The overall pattern of results described by Mosimann et al. (2004) indicates a general slowing when exerting volitional control (Level 5 processes in Findlay & Walker's model) over eye movements. But the data also reveal more than this. When bottom up input is pitted against top down mediation of reflexive responses, carrying out the requisites of top down instructions comes at some expense. When instructed to withhold saccades participants are able to comply, but only at the cost of inaccurate –hypometric– saccade targeting. When told to intentionally produce inaccurate saccades, likewise participants can do this –the saccade landing point more frequently being hypermetric in this case– but here the trade-off is in the form of longer saccade latencies. Even when setting out with the intention to momentarily fixate then swiftly disengage a pro-saccade target, the intermediate steps are slower than with self-corrected erroneous anti-saccades. One may liken these observations to competitive interactions in Findlay & Walker's framework. For example, the overriding supervisory mechanism to suppress saccade execution may increase activity in the Fixate centre; however an associated dampening of activity in the Move centre may be responsible for saccades which then fall short of the intended target location. Mosimann et al. (2004) also note that variance was much greater in these oculomotor parameters when implementing volitional control (as compared to spontaneous looking), a point which lends further support to the suggestion that top down training of eye movements may, in part, be disruptive.

There is other evidence, not purposefully set up to investigate competition between the Move and Fixate centres, which nonetheless suggests that top down intentions or bottom up signals can bias activity in one centre in comparison to that of the other. Tse (2002) has shown that although saccades are often generated towards the location of task-irrelevant abrupt onsets , this attentional capture is not obligatory. Indeed when the task at hand is to maintain fixation, no spontaneous eye movement is made towards the abrupt onset (this has close parallels with the delay condition described in Mosimann et al., 2004). Similarly, Lavie (2005) provides strong evidence that when the perceptual load of attended objects is high (i.e. the physical characteristics of stimuli being visually scrutinized are complex), the often reported interference of eccentrically positioned distracters can be eliminated. Whilst the former example from Tse may be linked to the Fixate centre taking priority through volition (i.e. top down), the latter example from Lavie is suggestive of the Fixate centre dominating due to stimulus attributes (i.e. bottom up).

The aforementioned research however is more connected to the Fixate centre "winning" and provides less evidence that the Move centre can take precedence. Is there comparable evidence that the Move centre can take priority at the expense of processing subserved by the Fixate centre? To some extent there is. Donovan, Manning, Phillips, Highman, & Crawford (2005) gave feedback to novice radiographers when performing a fracture detection task. Following this feedback (which showed them where they initially looked on the X-ray and for how long) their eye movements more closely resembled those of expert radiographers. Interestingly however, the use of an expert scanpath alone was not sufficient to give rise to an improvement on the fracture detection task. This suggests that advice which changes eye *movements* alone does not necessarily lead to improvements in performance, possibly because of the type of conflict between the Move and Fixate centres described. Work on 'Inattentional Blindness' (Mack & Rock, 1998) in the laboratory, moreover, confirms that people can fail to notice things they are directly looking at (Koivisto, Hyona, & Revonsuo, 2004); a phenomenon which has been coined Look-But-Fail-To-See in the literature on visual awareness in drivers (LBFTS, Brown, 2002). There remains a distinct possibility therefore that training people *where* to look (i.e.

encouraging activity in the Move centre) may degrade behaviour that is dependent on the Fixate centre.

Recall from Chapter I that several previous attempts to train eye movements were unsuccessful in their objectives (e.g. Abernethy & Wood, 2001; Quevedo et al., 1999). The argument presented above provides one viable explanation why. It is intuitive to think that training eye movements should be associated with advising people where to look, and that emphasis should be placed on efficiency by informing them to scan with alacrity. Indeed some authors and practitioners endorse this approach (e.g. Coyne, 1997; Mills, 2005). While this may doubtless be useful in making people faster, as we have observed with effects of Move Training presented thus far, it may obscure a hidden disadvantage in causing the trainee to be less efficient when fixating. The goal of the experiments presented in this chapter is to establish whether this is correct, and whether training directed at the Move centre in isolation leads to look-but-fail-to-see-like errors.

A final note on training eye movements, voluntary control (level 5 of Findlay & Walker's model) and automisation (level 4 of the model). The methods I am adopting define training as the implementation of strategies which effect eye movements to the benefit of task performance for the trainee. It has been pointed out already that this differs somewhat from training as conceptualised in the perceptual and visuomotor learning literature (see Chapter I, section 1.3-1.4), in that *learning* relates to undergoing hundreds of trials until the effects of practice have been consolidated. This is similar to the effects of practice that I have reported for untrained participants –it is probable that completing many more trials would improve performance further still in this group, drawing closer parallels to "learning" as synonymous with training. However, these terms are dissociated in this thesis; "training" referring to strategic advice, and "learning" referring to the effects of practice without guidance. I raise this point again here because it is possible that until learning is consolidated, thereafter affecting actions in an automated way, performance becomes worse before it gets better. Shapiro et al. (1989) report that oculomotor drills for a video game (reviewed in section 1.3, p.30) did improve game score, but only in the last third of a very lengthy experiment (i.e. after over 4hrs divided over multiple testing sessions). Combined with observations from sequence learning using a Saccadic Reaction Time (SRT) task, which show that when stimuli are presented in a novel sequence of spatial locations (compared to a learned sequence) SRTs increase (Kinder, Rolfs, & Kliegl, 2008), one may argue that prior to automisation via practice some facets of good performance must be sacrificed. This is consistent with the findings of Mosimann et al. (2004) reported above, and the implications are important because when eye movement training is advised for novice practitioners of complex tasks, it is often only suggested advice which people will not go away and practice for hours on end under controlled conditions. In certain circumstances this could have dire ramifications. For example, the advice offered to drivers by government agencies to repeat a left-right scanpath at junctions (U.K. Dept. for Transport, 2008a), similar to the advice to broaden visual search range with quick eye movements when driving (Coyne, 1997; Mills, 2005), could increase activity in the Move centre and decrease activity in the Fixate centre. Important objects (e.g. errant cyclists, pedestrians, other vehicles particularly motorbikes) could therefore be missed despite being fixated. The ultimate goal of such advice is desirable, and may well be attainable, but as we have seen it is questionable whether it will work initially unless other top down strategies are used simultaneously to compensate for the negative effects it may bring about.

Whether Move Training leads to a performance detriment as described, and whether this can be offset with combined Move *and* Fixate Training, will be assessed more directly in the next three experiments presented in this chapter. Again abstract arrays are used, and testing is carried out under controlled laboratory conditions. This will allow us to gain a thorough understanding of the factors involved, before moving on to examine the possibility that encouraging eye *movements* in drivers may cause detection failures (Chapter V).

4.1. Experiment 5 - Does Move Training hinder stimulus processing when two items are in direct competition?

One of the reasons we could not be certain whether the hypothesis that Move Training detracts from the ability to extract information when fixating is correct, is because in the previous experiments Move Training guided the eyes to the location of the target in the next trial. As such, target processing in trial *n* may not have been hampered by using a sequence which predicts target location in trial *n+1*, because the next target is not visible simultaneously. Moreover, in the last series of experiments Move Training afforded a large portion of the trial duration remaining to process the target because it removed the need for time consuming visual search to find it. Taken together these reasons cast doubt over whether the extended gaze durations reported for Experiment 4 were due to the type of conflict suggested between the Move and Fixate centres.

To remedy this, a novel paradigm was employed in which stimuli were placed in direct competition intra-, rather than inter-, trial. The task required visual search and stimulus discrimination, as previously, but this time a central letter was presented within a circular array of potential targets (see Fig. 4.1, panel A), and participants were required to start each trial by processing the central letter before searching the peripheral array for a digit amongst non-digits. This design was specifically chosen to require an initial discrimination judgement for the central letter (involving the Fixate centre) followed by visual search for the target digit (involving the Move centre) –these two items therefore vying for attention within the same trial.

When the peripheral target was an even number, the required response depended on the central letter: if the central letter was A, T, M, or V the correct response was to press the 1 key on the computer's number-pad; alternatively if the central letter was L, F, K, or N the correct response was to press the 3 key on the computer's number-pad. In contrast, the correct response to odd digits was unrelated to the central letter, a space bar press being required irrespective of the central letter displayed (these 'no-go' trial types served as catch trials to ensure participants searched the peripheral array and located the peripheral target). Eye movements were recorded while participants completed this task.

The paradigm used provides the opportunity to pre-inform participants about the sequence of locations the peripheral targets will appear in from one trial to the next; this forms the basis of training directed at the Move centre (see Fig. 4.1, panel B), which will be referred to as Move Training. The intention was to create a task where the demands placed on the Fixate centre by the initial letter discrimination judgment competed with Move centre activation when participants were instructed in Move Training. It is for this reason that correct answers were contingent upon *both* the central letter *and* the peripheral number; I sought a task where two items in the display are in direct competition because they are present simultaneously. If the basic task is to be comparable for an untrained group, and Move Training is to be beneficial in improving search performance yet detrimental in reducing information processing at fixation, a task such as the one used here is necessary.

It is predicted that the hypothesised competition induced by Move Training in our task will encourage disengagement from the central letter before it is fully processed. The most obvious way this effect could be revealed therefore is by reduced central gaze durations at the start of a trial, accompanied by fewer overall fixations and faster search times to locate the peripheral target. However, it is also conceivable based on considerable previous research (e.g. Engel, 1971; Eriksen & Hoffman, 1972; Koivisto et al., 2004; Motter & Holsapple, 2007; Posner, Snyder, & Davidson, 1980) that the absolute time spent on the centre upon trial commencement will not change, and the competitive interaction will be expressed as a premature shift of covert attention. Either way, insufficient initial processing of the central letter could lead to the detrimental performance of Move Trained participants in a number of ways: a decrease in accuracy, or participants could need to re-inspect the central letter more regularly after they have identified the peripheral target in order to respond correctly. These possible outcomes would advance our understanding of the eye movement statistics associated with looking but failing to see.

Given the hypothesis that Move Training may be detrimental to performance because of its affects on the Fixate centre, I also ask whether providing training directed at the Fixate centre, in concert with Move Training, can counteract any negative consequences that arise from Move Training alone. Training was directed at the Fixate centre by informing participants that the first set of letters (A, T, M and V) are all symmetrical around the vertical meridian, whereas the second set (L, F, K, N) are not. Therefore, when initially processing the central letter at the beginning of a trial, the discrimination judgment is reduced in difficulty. As noted before, this manipulation is introduced on the basis of previous research cited by Findlay & Walker (1999) as evidence for top down mediation of the Fixate centre (e.g. when a stimulus is unchanged but its informational load is decreased, fixation durations decrease also [Gould, 1973]). It is predicted that when directed in *both* Move Training *and* training aimed towards the Fixate centre (this combination of training strategies will hereafter be referred to as Both Training) that participants will no longer disengage from the central letter before it is fully processed, and as a result they will not need to re-inspect it as regularly in order to maintain accuracy. Both Training was chosen in preference to Fixate Training in isolation because I wished to demonstrate that any deficits on the task associated with Move Training alone could be ameliorated. In so doing I hope to show that the predicted visual search *benefits* of Move Training (in terms of faster search times and few fixations per trial) are attainable without any look-but-fail-to-see-like errors. As such, a Fixate-Trained-only group would provide little evidence of how visual training protocols could be improved, because without explicit direction in where to move the eyes, comparable benefits in visual search would not be expected. As was remarked in the last chapter, we already have evidence that training aimed at the Fixate centre independently is beneficial, both from Experiments 1 and 4 in this thesis, and circuitously from Gould and Zingale & Kowler (1973; 1987, respectively), who show that top down load increases fixation durations on stimuli that are unaltered. Because we are concerned with the training conditions which give rise to the best performance, and because we already have evidence that Fixate training works, Fixate-Trained-only groups are omitted henceforth.

Three groups of participants were tested in two blocks of trials. The first block served as a baseline to establish initial performance on the task. For the second block, one group of participants were told the Move Training strategy, another group were told Both Training strategies, and a third and final group were used as a control comparison, being given No Training throughout.

Although it is not central to the main hypothesis it is conceivable that participants may guess some of the experimental contingencies when they are not advised of the training strategies. Therefore participants were asked whether they noticed any of the rules which governed stimuli presentation upon debrief. This, coupled with a brief examination of typical scanning patterns within a trial, will address questions regarding explicit or implicit learning of the experiments' contingencies. Moreover, a simple examination of the typical scanpaths adopted will also highlight regularities in visual search behaviour. For example, one may predict on the basis of previous observations of scanpath uniformity (Foulsham & Underwood, 2008) that participants will search the peripheral array in a clockwise or counter-clockwise manner (see Findlay & Brown, 2006) prior to awareness of the predictable sequence in which the number target occurs.

One final manipulation was introduced into the design. For continuity with Experiment 4, and to re-examine the hypothesis that Move Training could lead to a performance detriment in two different ways, the availability of feedback was again manipulated. The logic behind this manipulation is the same as in the last chapter: when feedback is available participants may be more concerned with responding correctly than when it is not. As a result, with feedback, the 'pull' of the Move centre when directed in Move Training may extend the time need to process the central letter at the start of the trial; conversely, without feedback participants may be less concerned with responding correctly and therefore the 'pull' of the Move centre when directed in Move Training may cause them to disengage from the central letter before it is fully processed. With the first prediction (when feedback is provided), one would therefore expect an *increase* in the time spent processing the central letter at the start of the trial, but accuracy to be maintained. With the second prediction (when feedback is not provided), one would expect this pattern to switch, in line with the original predictions outlined above: a *decrease* in the time spent processing the central letter at the start of the trial, and therefore either a decline in accuracy, or an increased need to re-inspect the central letter at the end of a trial in order to respond correctly. Recall from Experiment 4 that when feedback was withdrawn there was a marginal reduction in the number of fixations per trial for the Move Trained group –this lends support to the idea that in the absence of feedback participants show greater adherence to following the predictable series of target presentation, therefore making the above predictions viable.

The ability to interact with the environment and evaluate the consequences of actions is particularly important in many areas of 'active vision' (Land, 2006; Land & Hayhoe, 2001) such as driving, sport, human-computer interfaces etc., and the source of error monitoring can be internal or external. These are further reasons feedback was manipulated in the current study. The second block of the experiment was equally divided into two counterbalanced sections, one in which visual feedback was always available, and one in which no feedback was provided.

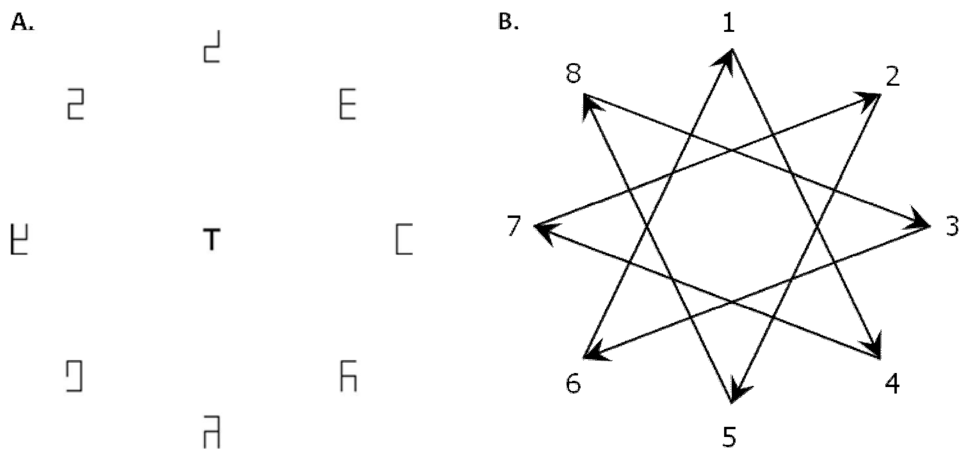

Fig. 4.1. An example of one stimulus as shown in a single trial display (A). The target (the only stimulus in the peripheral array that is a number, in this case the number 2) is located 45 degrees anticlockwise from the 12 O'clock position. The training directed at the Move centre (B). The numbers indicate place holder positions for the peripheral stimuli. From trial to trial the peripheral target number appeared in the following sequence: in trial one it was presented in position 1, followed by position 4 in trial two, then positions 7, 2, 5, 8, 3, 6 from one trial to the next (this is indicated by the arrows in the right panel of the figure). This sequence is repeated throughout all experimental blocks.

4.1.1. Method

Participants

Thirty eight paid participants (with a mean age of 23 years, range 18-29; 26 female) were recruited from the University of Nottingham's student population. All participants reported normal or corrected-to-normal vision.

Stimuli & Apparatus

There were five hundred and twelve individual stimuli in total; the central letter could be one of eight possibilities: A, T, M, V, L, F, K or N; the peripheral number target could appear in one of eight locations around the centre, and was one of eight numbers in 'calculator-style' font: 0, 2, 3, 4, 5, 6, 7 and 9 (1 and 8 were not used because they contained too few, and too many component lines respectively, which could unfairly assist their detection). Zero was classified as an even number and participants were made aware of this. All of the factors differentiating the stimuli mentioned above were represented with equal probability.

Twenty four non-digit distracters were created by removing one or more component lines from the number 8 (see appendix 8.2). Each distracter had approximately the same visual footprint, and different distracters occupied the remaining seven peripheral locations of the stimulus that did not contain the target. Which distracter occurred in which position was determined at random.

All letters and digits subtended 0.8° visual angle horizontally. The peripheral shapes subtended 1.6° vertically, while the central letters subtended 1.2° vertically. The centre of the central letter was coincident with the centre of the display. The peripheral shapes were located on the perimeter of an imaginary circle with a radius of 10° visual angle from the centre. Peripheral items were arranged of this radius at 45° increments around the centre (example stimulus Fig. 4.1A, not to scale).

A PC operating with a Pentium 3 processor was used to run the experiment via E-prime software. Stimuli were presented on a 19″ Samsung SyncMaster LCD screen, running at 1024 x 768 pixel resolution. A desk mounted SMI Red-Eye III eye tracker was used to record eye movements of the right eye at 50Hz. Fixations were defined as periods of ocular stability in-between saccades with a minimum duration of 80 milliseconds.

Design

The experiment was divided into two blocks of 128 trials. Baseline performance was assessed in Block 1, with no eye movement training being given. In-between Block 1 and 2 Training was provided for the Move Trained (MT) and Both Trained (BT) groups; the No Training group (NT) acted as a control.

The MT group (N=14) was informed that the target would appear in the predictable sequence shown in Fig. 4.1B from one trial to the next. The target was presented in this order with 100% probability throughout both blocks of the experiment for each group of participants. The BT group (N=10) were given an additional strategy to that of the MT group; they were made aware that the letters A, T, M and V (to which the same response is required) are all vertically symmetrical, whereas the letters L, F, K and N (which also share the same required response) are vertically asymmetrical. The NT group (N=14) were given neither of these strategies.

Feedback was also manipulated in accordance with the predictions outlined when introducing this experiment, and to take account of controversy surrounding the ability to monitor errors when carrying out visual and motor tasks (Hajcak, Holroyd, Moser, & Simons, 2005; van Veen, Holroyd, Cohen, Stenger, & Carter, 2004). It was also thought it prudent to include this measure because the final experimental chapter of this thesis (Chapter V) will relate the results obtained here to driving scenarios. If the investigation is to be related to the look-but-fail-to-see accident causation factor in driving (Brown, 2002), it is necessary to parallel the sources of error monitoring that drivers use (i.e. external -such as flashing speed warnings, traffic lights, and beeping horns; and internal –such as recognising when you braked too late, or pulled out too early even though no accident transpired).

Feedback was a within groups factor, with half of block 2 containing feedback (FB) and half not (NFB). The order of this manipulation was counterbalanced across participants. Throughout block 1 feedback was always given, by way of a red (incorrect) or blue (correct) transient screen after each trial (‘time-outs’ were considered incorrect). For NFB trials the blue or red mask was replaced by a grey mask in all instances, such that feedback was no longer available. The different feedback masks used were identical to Experiment 4.

With the exception of the sequence of peripheral target location being predetermined, stimuli were selected quasi randomly. Catch trials (where the peripheral target was an odd number) occurred with $33.\dot{3}$ % probability while trials with an even number target occurred with $66.\dot{6}$ % probability. As the number of trials per block is smaller than the number of stimuli not all stimuli occurred within a block of trials.

Several dependent variables contributed to the measures taken from the design. Behavioural data in terms of manual reaction times and accuracy were recorded. Several measures of eye movements were also taken. The stimulus array was divided into regions of interest for eye tracking analysis. A circle, with a radius 2.9° visual angle from the centre of the display, was created within which any fixation made was classified as a fixation with the purpose of central letter processing. Initial central gaze duration, the cummulation of fixation durations from the first fixation on the central letter to the last fixation before this region is left, was calculated. After this initial period of inspection any fixation made within this central region was classified as a re-fixation. The mean re-inspection duration (i.e. the average of re-fixation durations for all trials in an entire block, including those in which no re-fixation occurred) was calculated as well as the average number of re-fixations per trial.

Finally, overall visual search performance was assessed, firstly by analysing the average number of fixations per trial, and secondly by analysing the time taken to fixate the peripheral target from the start of the trial. The latter of these measures was calculated by creating regions of interest around the peripheral array items. If a fixation was made outside the area of the imaginary circle designated for the central letter, but within the area of another eccentric circle with a radius 5.8° visual angle from the centre of the display, it was classified as being unrelated to the processing of any of the displayed items in the stimulus array. Beyond the second eccentric circle fixations were divided into those on the peripheral number target and those on the distracters. This was done by splitting the stimulus array into regions 22.5° (of a total 360° for the entire stimulus array) either side of centre of the peripheral shapes. If a fixation landed within the target's region it was flagged, therefore allowing the time taken to fixate the target to be calculated. To compliment these parametric measures of visual search performance, representative scanpaths of visual search behaviour within a trial will be shown for example participants.

For purposes of analysis the data collected will be treated in terms of changes in block 2 relative to baseline –the difference score, as described previously (overall means will be given also). The relative change from baseline to either the FB or NFB sections of block 2 controls for individual differences in performance as a function of training, or, in the case of the NT group, exposure alone.

Procedure

On arrival informed consent was obtained from the participants. Detailed instruction was available on the computer screen explaining the task, and the experimenter was present throughout to ensure participants understood what they had to do. After agreeing to take part and confirming that they understood the task the experimenter calibrated the eye tracker (a chin rest was used to maintain a stable and fixed viewing position of 70cm from the screen throughout the experiment). Following calibration participants were initially given a practice block of 30 trials which were identical to the experimental blocks described below. Once participants had completed the initial practice block, and the experimenter was satisfied that they understood the task they could proceed.

A fixation cross was presented only at the start of a trial block. A stimulus was then selected according to the stipulations outlined in the design section above. The stimulus remained on the screen until a response was made or for a maximum duration of 10s, following which a feedback mask was presented for 200ms. Stimulus presentation followed by feedback continuously cycled until the end of a block.

Participants were required to begin each trial fixating the central letter, before searching the peripheral array for the target number. When A, T, M, or V were presented in the centre, and the peripheral target was an even number, the correct response was to press the 1 key on the keyboard number-pad; when L, F, K, or N were presented, and peripheral target was an even number, the 3 key on the number-pad was the correct response. When the peripheral target was an odd number the trial was a catch trial, and the correct response was to press the space bar irrespective of which letter was displayed. Participants were asked to respond as quickly and accurately as possible throughout.

Participants completed the baseline block first, after completion of which the MT and BT groups received their respective training via on screen instructions. The experimenter also provided explanation if required. Participants were then given a further 30 trials of practice to become familiar with using the training suggested to them. The NT group was given an additional 30 trials practice also to ensure equal exposure to the task. Following this practice the experimenter re-calibrated the eye tracker as before.

The second block proceeded next. As Feedback was counterbalanced the order of feedback availability in block 2 varied between participants, they were always informed however of whether the trials they were about to complete contained feedback or not by on screen instructions.

On completion of the experiment participants were debriefed as to the aim of the experiment and its hypotheses. A short questionnaire was also completed in which generic demographic information was collected, along with information about whether the experiment's contingencies were guessed.

4.1.2. Results

Reaction Times

Practice trials, catch trials and anticipatory responses (RT <200ms) were removed before analysis for all analyses described. Although the behavioural data collected was analysed in terms of difference scores, summary statistics showing the means in each condition are given below (Table 4.1).

The relative effect of training (or practice for the NT group) was calculated, as before, by subtracting the participants' mean baseline (block 1) RT from their mean RT in both parts of block 2 (i.e. FB and NFB). A negative value therefore reflects a decrease, whereas a positive value reflects an increase. These RTs were analysed by a 3x2 mixed factorial ANOVA, with 3 levels of Training and 2 levels of Feedback (this analysis was repeated for all dependent measures taken).

A significant main effect of training was observed (F (2, 35) = 4.5, *MSE* = 341062, p = 0.018), reflecting the greater improvement in RT for the trained groups (MT $\overline{x_{Block_2} - x_{Block_1}}$ = -799ms, S.E.M = 110.4; BT $\overline{x_{Block_2} - x_{Block_1}}$ = -861ms, S.E.M = 130.6) compared to the NT group ($\overline{x_{Block_2} - x_{Block_1}}$ = -412ms, S.E.M = 110.4). Post-hoc comparisons with Tukey's HSD confirmed that while the trained groups both differed significantly from the NT group (p's <0.05), the MT and BT group did not differ from each other (p = 0.931). There was no main effect of feedback, and feedback did not interact with training.

To check that no group had a quasi advantage in their ability to perform the task from the outset, baseline (block 1) RT's were compared by a one-way ANOVA with training as the grouping variable. No baseline differences were observed between groups for RT's, or any of the measures reported henceforth.

Accuracy

No significant main effects were found in the accuracy analysis, neither did the factors interact. Accuracy was high however ($\bar{x}$ = 93% correct overall, Std Dev = 5.3). See Table 4.1 for overall means in each condition.

Training group		Block 1 (baseline)	Block 2	
			Feedback	No Feedback
NT	Reaction Time	3258 *143*	2890 *148*	2802 *150*
	Accuracy	92 *1.5*	92 *1.2*	95 *1.2*
MT	Reaction Time	3279 *113*	2433 *128*	2524 *135*
	Accuracy	92 1.2	92 1.1	93 1.2
BT	Reaction Time	3416 *188*	2481 *142*	2628 *145*
	Accuracy	93 *1.5*	95 *1.2*	94 *1.8*

Table 4.1. Mean reaction times (ms) and accuracy (%) for each group in each condition. Standard errors are italicised.

Eye Movement Recordings

To properly understand the behavioural data obtained in the context of eye movement control it is necessary to examine certain statistics of visual search and central letter processing. In addition to the removal of practice, catch, anticipatory, and incorrect trials, trials in which the peripheral target was not fixated, the initial central gaze duration on the letter was <50ms, and the central letter was not fixated within 4 fixations, were also excluded prior to analysis of the eye movement data. Respectively, these criteria reduce the possibilities that participants were locating the target in peripheral vision, spending an insufficient time foveating the centre at the start of the trial, or searching the peripheral array first (even though they were specifically told not to do this). Following these exclusions an average of 36 trials contributed to each participant's cell means for the eye movement measures taken. If a participant had less than 10 trials contributing to their cell mean for the baseline, feedback or no-feedback blocks they were removed from the subsequent eye movement analysis. Loss of calibration among certain participants meant that 7 were excluded due to this criterion, 3 from the NT group and 4 from the MT group. One participant was also excluded (from the BT group) due to not completing the task properly (he/she said they found it easier to locate the peripheral target first, and continued to do this even though they were explicitly told to always begin with the discrimination judgement on the central letter). Following removal of these participants an average of 40 trials contributed to the cell means. Although the eye movement data was also analysed in terms of difference scores the means in each condition are given below (Table 4.2).

Training group	Eye movement statistic	Block 1 (baseline)	Block 2	
			Feedback	No Feedback
NT	Number of fixations per trial	9.6 *0.4*	8.9 *0.3*	8.8 *0.3*
	Time to first target fixation	1963 *137*	1702 *138*	1651 *134*
	Initial central gaze duration	473 *52*	397 *36*	455 *58*
	Re-inspection duration	186 *33*	143 *28*	185 *39*
	Number of re-fixations per trial	1.1 *0.2*	0.7 *0.1*	0.9 *0.2*
MT	Number of fixations per trial	9.4 *0.3*	6.9 *0.3*	6.9 *0.4*
	Time to first target fixation	1828 *226*	1197 *181*	1207 *180*
	Initial central gaze duration	643 *102*	608 *96*	664 *118*
	Re-inspection duration	146 *31*	187 *48*	133 *39*
	Number of re-fixations per trial	0.7 *0.2*	0.7 *0.2*	0.6 *0.2*
BT	Number of fixations per trial	10.2 *0.8*	6.8 *0.6*	7.2 *0.5*
	Time to first target fixation	1967 *173*	1132 *121*	1125 *135*
	Initial central gaze duration	399 *38*	539 *140*	472 *98*
	Re-inspection duration	178 *51*	163 *51*	203 *59*
	Number of re-fixations per trial	1.0 *0.3*	0.7 *0.2*	0.9 *0.2*

Table 4.2. Summary statistics for the measures of eye movements taken (timings in ms). Means are shown for each group in each condition with standard errors italicised.

Overall visual search performance

The average number of fixations per trial gives an indication of search efficiency. Analysis of the relative changes in these data revealed a significant main effect of training only (F (2, 27) = 8.4, *MSE* = 3.6, p = 0.001), highlighting that the trained groups (MT $\overline{x_{Block_2} - x_{Block_1}}$ = -2.5, S.E.M = 0.4; BT $\overline{x_{Block_2} - x_{Block_1}}$ = -3.2, S.E.M = 0.4) make less fixations following training than the reduction afforded by practice alone (NT $\overline{x_{Block_2} - x_{Block_1}}$ = -0.8, S.E.M = 0.4). Tukey HSD Post-hoc comparisons confirmed these differences (NT vs. MT, BT: p<0.05; MT vs. BT: p = 0.54).

Visual search performance can also be assessed by looking at the time from commencement of the trial to fixation of the peripheral target. The relative change analysis for this measure revealed a significant main effect of training only (F (2, 27) = 6.7, *MSE* = 234948, p = 0.004), with the trained groups (MT $\overline{x_{Block_2} - x_{Block_1}}$ = -625ms, S.E.M = 108.4; BT $\overline{x_{Block_2} - x_{Block_1}}$ = -838ms, S.E.M = 114.2) improving more than the NT group ($\overline{x_{Block_2} - x_{Block_1}}$ = -286ms, S.E.M = 103.3). Post-hoc comparisons with Tukey's HSD revealed differences between the NT and BT groups only (p = 0.004); the comparison between the NT and MT groups narrowly failed to reach conventional statistical significance (p = 0.078), and the MT and BT groups did not differ (p = 0.38). This pattern of results complements the RT analysis, demonstrating the improved search efficiency of the trained groups.

Visual Scanning Behaviour

To relate the measures of visual search performance outlined above to eye movement patterns, typical scanpaths within a trial are plotted below for two example participants (Fig. 4.2). Although detailed statistical analysis of these scanpaths is outside the scope of this investigation (see Foulsham & Underwood, 2008 for a more comprehensive approach) they do reveal a number of interesting findings pertinent to the hypothesis. First, given the circular arrangement of stimuli in the periphery, participants commonly favoured a clockwise or counter-clock clockwise eye movement sequence (when untrained), as predicted. Such visual search behaviour is similar to what has been previously described as a 'convex- hull' scanpath, where participants predominantly search the perimeter of an array of items making frequent forays into the centre (Findlay & Brown, 2006). Given the layout of the stimuli this is not so surprising; however, there were certain noteworthy characteristics of participants' fixation sequences en route. Fig. 4.2A (left panel) shows that in trial 52 of the baseline block subject 13 (from the NT group) commenced searching the periphery at target position 6, continuing up to position 8 before backtracking to position 7 to recheck the distracter there. After doing so the original search did not resume from where it left off, instead this participant moved over to the opposite side of the display and began to search in a clockwise order once more. An interesting observation of the search behaviour adopted in this trial is that once this subject reached the original location at which the search began, they remembered that they had already searched the left hand side of the display and continued up to the remaining segment that was yet to be inspected. This is an excellent example of an entirely exhaustive search where all possible regions were inspected before the target was found. As was frequently the case, the target fixation was the penultimate fixation of the trial, the final fixation being a re-fixation on the central letter.

Despite the minor practice effects of the NT group reported above it can also be seen that, even towards the end of block two, the same untrained participant failed to notice the predictable sequence of target presentation. This is nicely shown in Fig. 4.2A (right panel) where the participant began an anti-clockwise search on the opposite side of the screen to the target and still passed over the target after it was eventually fixated, only backtracking to its location two fixations later. Indeed, when completing the debrief questionnaire no subject explicitly reported guessing either the predictable order of target presentation or the symmetry rule which applied to the central letter.

The visual search behaviour of the MT group at baseline was similar to that of the NT group. The example trial from subject 21 illustrates this (Fig. 4.2B, left panel). During block two (right panel) however the benefit of MT is apparent: Subject 21 commenced searching the periphery by returning to the target location of the previous trial, then promptly moved to the target location of the trial in hand. This strategy was quite common and is interesting because it identifies that subjects sometimes used the target location from the previous trial as a placeholder for the up-coming trial. This preference may suggest that with this task executing saccades to the exact location dictated by the MT strategy is more demanding than returning to the previous target position for guidance.

The final point of interest in the visual scanning behaviour of the MT participants is that they often made consecutive re-fixations at the end of a trial, typically alternating between the target and the central letter several times before responding. This is important as it is in-line with the predictions of the main hypothesis. Eye movements of this type are exemplified in the bottom right panel of Fig. 4.2B

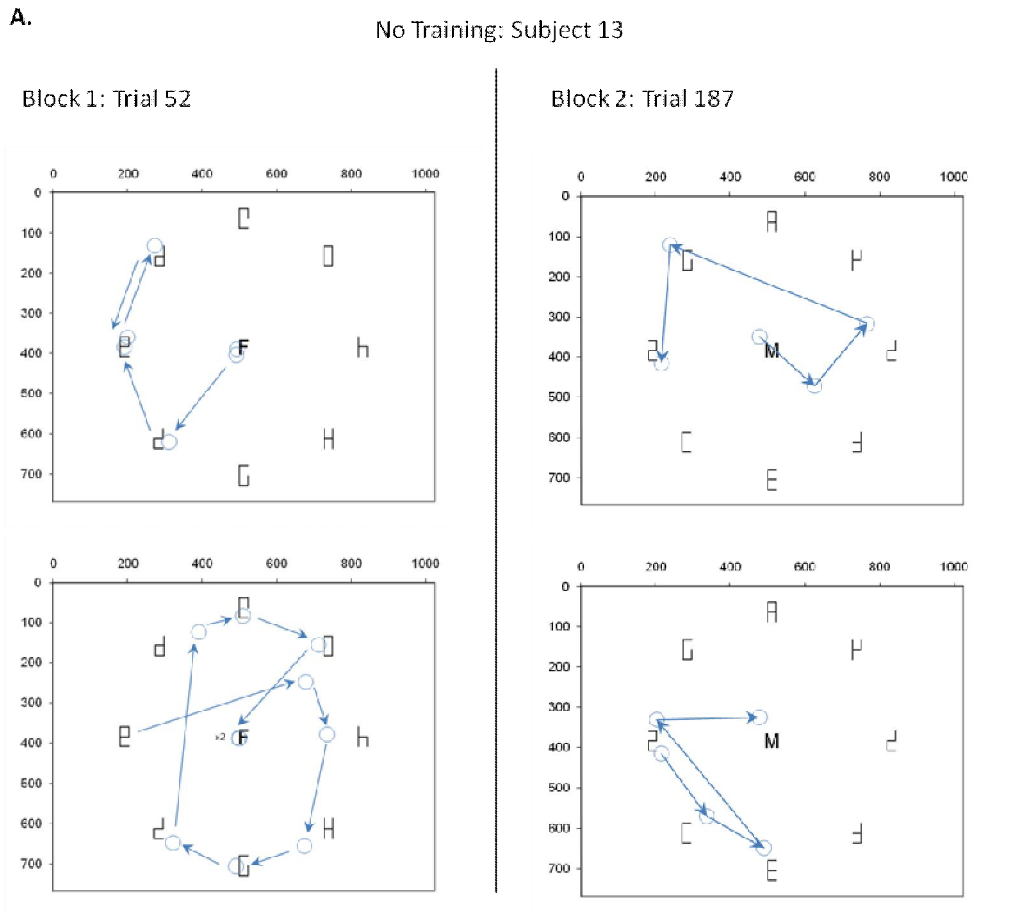

Fig. 4.2. The sequence of eye fixations made by an untrained participant (A) in Block 1 (left panel) and Block 2 (right panel). Arrows indicate the order of fixations in the sequence not saccades per se. Each panel should be read from top to bottom, the first fixation in the bottom panels showing how the search continued from the last fixation in the top panels (in reality the sequence was continuous but is subdivided here to avoid clutter and overlap). Where two fixations are consecutive, overlapping and not easily discernable from subsequent return fixations 'x2' is indicated on the figure. The *x* and *y* axes of each quadrant represent screen dimensions in pixels (1024x768 respectively).

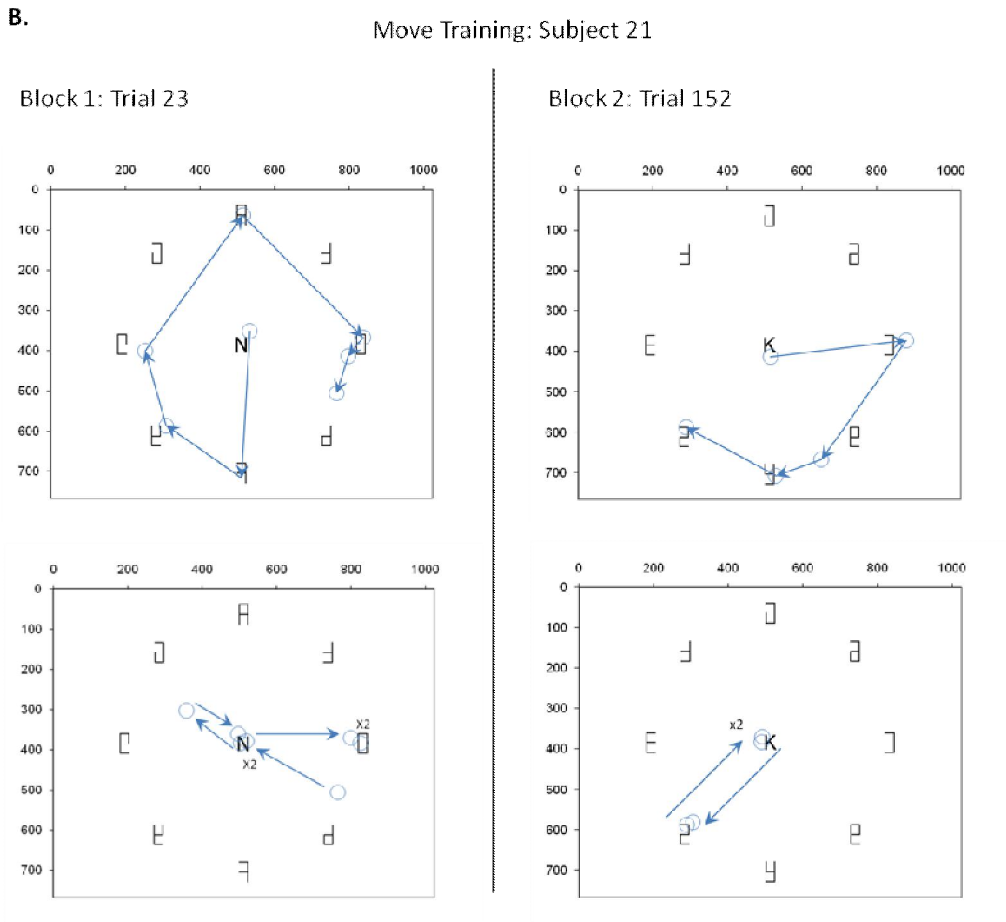

Fig. 4.2 continued. The sequence of eye fixations made by a participant from the MT group (B) in Block 1 (left panel) and Block 2 (right panel). Arrows indicate the order of fixations in the sequence not saccades per se. Each panel should be read from top to bottom, the first fixation in the bottom panels showing how the search continued from the last fixation in the top panels (in reality the sequence was continuous but is subdivided here to avoid clutter and overlap). Where two fixations are consecutive, overlapping and not easily discernable from subsequent return fixations 'x2' is indicated on the figure. The *x* and *y* axes of each quadrant represent screen dimensions in pixels (1024x768 respectively).

Central letter processing: Initial central gaze duration

The summation of fixation durations for consecutive fixations made within the central letter's region of interest, from the first fixation within this area until a saccade is made outside of it, gives an indication of how efficiently the central letter is initially processed. It also allows one to infer whether the MT strategy employed exerts any influence over this initial processing. These data were extracted from the eye movement recordings; however, the relative change analysis revealed no significant differences, and is not reported further.

In an attempt to see whether other measures of initial letter processing yielded any significant results both the mean number of fixations of which the central gaze duration consisted, and the mean fixation duration for fixations contained within the central gaze duration were extracted and analyzed. Again however the relative change analysis on these data revealed no significant effects. Therefore one must conclude that neither training, feedback, nor a combination of these factors interacting, affects the duration or amount of fixations made on the central letter in the first instance.

Re-Inspections of the central letter

Apart from fixations classified as comprising the initial central gaze duration, any other fixation made on the central letter was identified as a re-fixation. For continuity, and to avoid any further data loss, I chose to calculate mean re-inspection durations (the average of re-fixation durations for all trials in an entire block, including those in which no re-fixation occurred). This approach was considered more logical than calculating the mean duration of re-fixations when they occurred, since I did not expect the NT and BT groups' re-fixations to be as numerous. Therefore this measure keeps the number of trials contributing to each cell mean constant, favouring fair comparisons. However, it should be noted that the effects on re-inspection durations reported below remain for the more conventional measure of mean re-fixation duration also. These data are not presented however because there were indeed too few trials contributing to certain participants cell means.

There was no main effect of training in the relative change analysis for the re-inspection duration measure, neither was there a main effect of feedback. Crucially however, these factors did interact ($F(2, 27) = 3.8$, *MSE* = 4029, $p = 0.036$). This interaction is charted in Fig. 4.3 and reflects the fact that the MT group has increased mean re-inspection durations, but only when external visual feedback was presented. In contrast the provision of feedback did not increase the mean re-inspection durations of the other two groups, on the contrary, it seems to reduce them. This suggests that feedback is beneficial unless trained on the Move centre in isolation. For the NT group and to some extent the BT group, when feedback was available the initial time spent processing the central letter seems sufficient, therefore these groups showed a reduced need to return to it. When the MT group received feedback however the initial time spent processing the central letter seems less than optimal, therefore these participants needed to re-inspect it for longer durations in order to respond correctly.

When feedback is not provided however, this pattern changes: all groups now show more of a trend towards re-inspecting for comparable durations to those observed at baseline (i.e zero on the y axis of Fig. 4.3). In fact when feedback is not provided the trend described above appears to reverse somewhat.

To assess these results post-hoc tests were carried out. Two one-way ANOVAs were conducted, one comparing the differences between groups in the FB condition, and one comparing the differences between groups in the NFB condition. Only the first of these yielded a significant between groups effect ($F(2, 27) = 4.7$, *MSE* = 4081, $p = 0.018$), and Tukey HSD post-hoc comparisons showed that the difference in this analysis lies with the increase in mean re-inspection durations for the MT group and the decrease in mean re-inspection durations for the NT group ($p = 0.015$); the NT group did not differ from the BT group ($p = 0.609$), and the MT group did not differ from the BT group ($p = 0.150$). These analyses confirm that the MT group re-inspects the centre for longer than the NT group, but only in the FB condition.

The same analysis was conducted on the average number of re-fixations per trial (see Fig. 4.4). There were no main effects, and neither was the interaction significant. However, because there is reason to believe that the MT group re-fixate the centre more regularly than the NT group, two independent samples t-tests were carried out. The first compared the difference between the NT and MT groups in the FB condition, and was significant ($t_{19} = -2.5$, $p = 0.021$); the second compared the same groups in the NFB condition, and was not significant ($p = 0.435$). This mirrors the re-inspection duration analysis. Moreover, although all groups showed a slight decrease in re-fixations, a finding which is consistent with practice at the task, the MT group showed the smallest reduction. This therefore demonstrates that the re-inspection duration results described above are not the artefact of a trade-off where the longer re-inspections of the MT group are a consequence of this group making less re-fixations numerically.

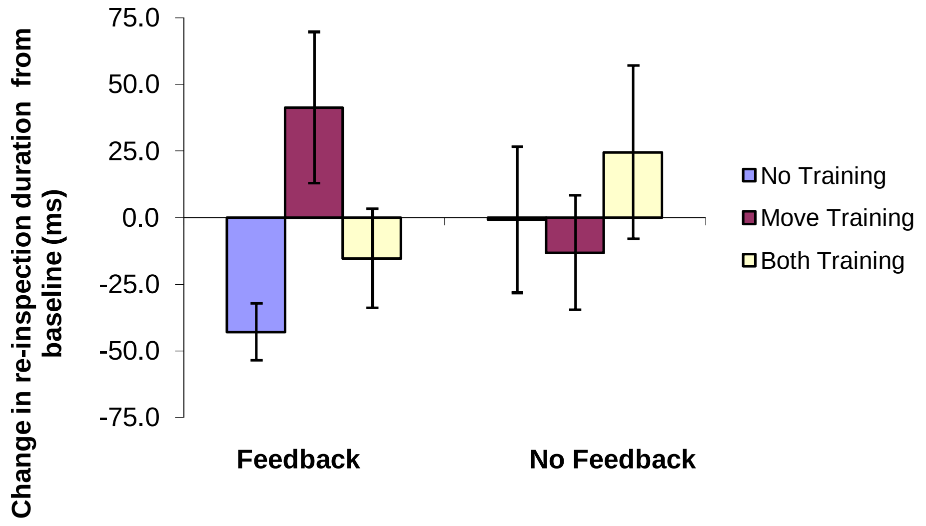

Fig. 4.3. Relative change from baseline in mean re-inspection durations for each group, across feedback conditions. Error bars show standard error of the mean.

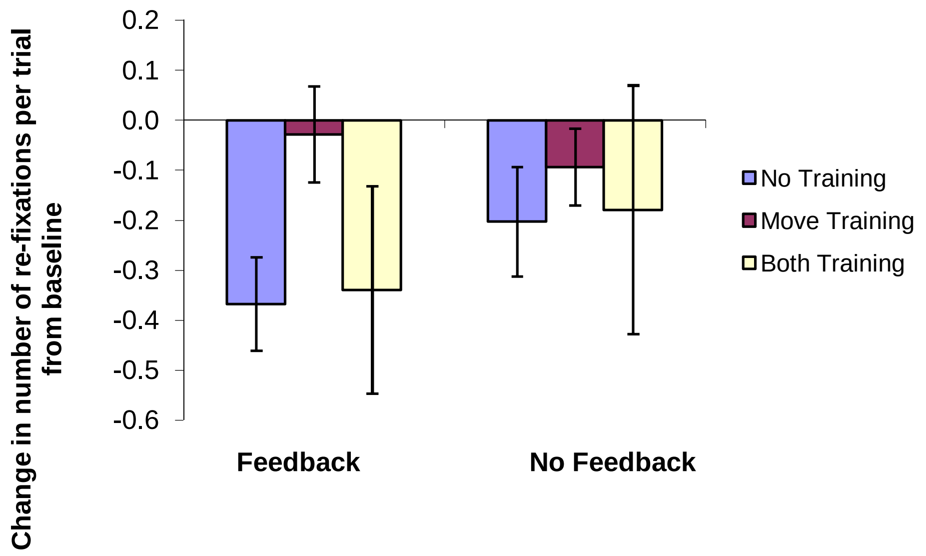

Fig. 4.4. Reduction from baseline in the mean number of re-fixations per trial for each group, across feedback conditions. Error bars show standard error of the mean.

4.1.3. Discussion

Several predictions were made from the outset regarding the consequences of training eye-movements. It was hypothesised that isolated eye movement training directed towards the Move centre of Findlay & Walker's (1999) model would in some way degrade the ability to process the centrally located letter, due to competition between the need to fixate this item (or Fixate centre activity) and the urge to saccade towards the known location of the peripheral target (or Move centre activity). It was predicted that this effect would be exposed in one of two ways. First, it could *reduce* the time spent processing the central letter at the start of the trial, either leading to a reduction in accuracy, or MT participants re-inspecting the central letter more regularly in order for accuracy to be preserved. It was thought that these potential outcomes would be linked to the NFB condition, because, without feedback, participants would be less anxious about responding correctly and more ingrained in following the predictable sequence of target presentation. The second suggested way in which training directed at the Move centre could affect the initial processing of the central letter was through *extending* the time normally needed to scrutinize it for the discrimination judgement. This prediction was linked to the FB condition because it was reasoned that here participants would try harder to maintain accuracy, therefore the 'pull' of the Move centre when directed in MT would compete with the desire to fully apprehend the response required to the central letter, giving rise to longer initial central gaze durations.

Evidence for the first prediction (premature disengagement from the central letter) was found, not in reduced accuracy, but with the re-inspection durations. The data shows that, although all groups showed comparable processing time on the central letter in the first instance (reflected in the initial central gaze duration measure), the MT group alone failed to process the item adequately within this time, needing to re-inspect it for longer in order to respond correctly. However, this result did not follow the expected pattern with respect to the feedback manipulation; in fact, the opposite was observed: re-inspection durations increased when feedback was provided, implying processing of the central letter was less than optimal in this condition (or at least that subjects *thought* it was less than optimal). When feedback was not available re-inspection durations for the MT group were comparable to controls. There was no evidence for an increase in central gaze durations in either of the feedback conditions for the MT group.

How might these results be accounted for? It is feasible that the explanation could be related to the ability to regulate error monitoring for the MT group. Perhaps when executing the highly coordinated sequence of eye movements and stimulus processing required the MT group are better able to carry out the task when they can internally regulate whether their responses are correct. External feedback therefore might lead to a bottleneck in a capacity limited system (see Pashler, 1994) where the competing demands to remember the sequence of eye movements required, the response to be made to the central letter, and to process the feedback mask, overload cognitive resources. As a result of this conflict it is the initial processing of the central letter which is hindered for the MT participants, a problem which is remedied by looking back towards the letter for longer. This does not occur for the NT and BT groups however because for these participant groups one of the factors causing the bottleneck is removed: the NT group does not have a sequence of eye movements to remember, and the difficulty of processing the central letter is reduced for the BT group. As a result the feedback mask has an interfering effect on the MT group only, while it assists the NT and BT groups.

Interestingly, previous research has shown that when a voluntary saccade is being planned, oculomotor capture from an abrupt onset is likely (Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999), whereas this capture does not occur when the task is to remain fixated (Tse et al., 2002). Although the feedback masks used here were global transients, maybe they cause a similar process of interference for the MT group when voluntarily executing saccades dictated by the Training Sequence. This may not occur for the other two groups however because competition between the Move centre and Fixate centre is less, and there are less cognitive demands causing a bottleneck.

The argument presented above suggests that the MT group prefers to internalize error monitoring. However, how might this process be carried out? It is conceivable that, when feedback is not provided, MT participants have a higher likelihood of generating feedback Error Related Negativity (fERN - Holroyd et al., 2006), a frontal lobe ERP component associated with evaluating the outcomes of actions in the absence of external feedback. Further research incorporating ERP recordings with eye movements training would reveal if this is the case, and whether the higher and less specified levels of Findlay & Walker's (1999) model should be revised to take account of this possibility.

On the surface it appears that directing eye movement training towards the Move centre of Findlay & Walker's (1999) model is beneficial: it improves visual search performance in terms of reaction times and overall search efficiency, desirable goals for any eye movement training strategy; yet conversely, more subtle detrimental effects on the processing of individually fixated items (in this case the central letter) may be missed. This might explain why some previous attempts to train eye movements may not have had the desired outcomes (Chapman et al., 2002; Donovan et al., 2005; Quevedo et al., 1999). Moreover it should raise awareness amongst researchers when developing eye movement training regimes for use in applied settings, because it suggests that the emphasis often placed upon moving the eyes (e.g. Coyne, 1997; DfT, 2008a; Mills, 2005) may be misplaced. It appears that a more effective way to employ eye movement training is to concentrate efforts towards the Fixate centre *as well as* the Move centre. When this is done (as demonstrated with the BT group in the present experiment) the deficit associated with MT alone is abolished. The training directed at the fixate centre, employed by the BT group, seems to reduce the processing demands of the central letter despite its appearance remaining unchanged. Once again, this concurs with similar reports of higher influences on the Fixate centre when stimulus characteristics are kept constant (Gould, 1973; Zingale & Kowler, 1987).

Therefore, the pattern of results observed suggests that training directed at *both* the Move *and* Fixate centres of Findlay and Walker's (1999) model is advisable. Although MT in isolation can be beneficial, this was only the case when visual feedback was not pertinent to the task at hand. Hence, as particularly in applied settings awareness of visual reinforcement is vital when interacting with the environment, it seems less likely that eye movement training directed solely at the Move centre will be helpful. Clearly however there are big differences between the experimental task used here and 'real life' scenarios; the characteristics of stimuli were exactly controlled here therefore it was known in advance precisely what training strategies to advise. Nevertheless, despite the differences between this study and applied contexts, it is evident that additional focus from domain specific experts should be given to the processing of fixated items, in concert with assisting in the ability to visually locate them which has been a predominant drive in recent years. Incorporating this advice into existing training regimes may be as simple as advising people to "look for longer". For instance, drivers could be advised to… "Look right CHECK, look left CHECK, then right again" (cf. DfT, 2008a).

In light of there being no differential effect of training on the initial central gaze durations, it is necessary to consider one final point: how does MT affect the processing of the central letter at the start of a trial? Two possibilities emerge about the way in which inspection of the letter may be degraded.

First, one could relate the suggested competition between the Move and Fixate centres to some form of covert attention shift towards the saccade target before the eyes move. This idea can be supported by considerable evidence about covert attention (e.g. Engel, 1971; Eriksen & Hoffman, 1972; Koivisto et al., 2004; Motter & Holsapple, 2007; Posner et al., 1980). Koivisto et al. (2004) used an inattentional blindness paradigm to show that when participants fixate the central region of a display and orient covertly to peripheral targets, they fail to notice an unexpected stimulus even when it is always presented centrally at the point of fixation. A similar process of 'looking but failing to see' may well account for the present results. However, because with the present task participants were not explicitly instructed to keep their eyes fixed at the centre, an interesting conclusion emerges: namely, that the delay between a covert shift of attention and a proceeding saccade can vary according to task demands even when subjects are free to move their eyes. The issue of whether the time course of covert shifts can vary is somewhat controversial in the literature, though some of the modelling work on eye movements in reading are able to account for such effects (see Chapter I, section 1.1). Also, *Spatial Selection* in Findlay & Walker's model provides a component which could potentially accommodate variability in covert attentional shifts (this feature of Findlay & Walker's framework operates much like the traditional spotlight or zoom lens models of attention, selectively enhancing a spatially restricted region before the eyes move).

There is another possibility, which does not require reference to differences in covert attentional shifts. Perhaps training directed at the Move centre reduces the efficiency of fixations contained within the initial central gaze duration, in a similar way as proposed with the extended gaze durations of the MT group in the last chapter (i.e. Experiment 4: the MT group, despite comparable fixation durations on the target, inspected it for longer than the NT and BT groups to work out the response, implying processing was less efficient). However, because two locations compete for resources in Experiment 5, it is possible that the MT participants are drawn away from the central letter too soon, without spending the extra time needed to offset the reduced effectiveness of each fixation caused by Move–Fixate competition. I will address whether this account is more likely than the covert attention explanation in the final experiment of this chapter. However, the most obvious question to tackle next is, does accuracy reduce for the MT group when they are no longer able to re-inspect the central letter? One would expect this to be the case in the FB condition based on the arguments presented above.

4.2. Experiment 6 - Is it possible to force a reduction in manual response accuracy due to Move Training?

Given that re-inspection durations on the central letter increase when training is directed towards the Move centre in isolation, one must ask whether the reason for this is for accuracy to be preserved. If Move training causes premature disengagement from the central letter at the start of the trial, one would expect accuracy to decline for this group only if they can no longer re-inspect the letter at the end of the trial. Experiment 6 will address this question by removing the central letter from the display after the initial period of inspection, thereby eliminating re-fixations of the letter. If the hypothesis is correct this should force a reduction in accuracy for MT participants.

There are other reasons why this manipulation could be important also. First, we cannot be sure whether *all* groups need to look back at the letter to confirm their responses, because peripheral vision may be used at the end of the trial instead of overt re-fixations[3]. While re-checking via peripheral vision seems unlikely for the BT group because they have identical training directed towards the Move centre, one can imagine that the NT group have longer to acquire the right information from the central letter through peripheral vision while they are scanning the circular array of potential targets. Indeed one might expect the competitive interaction between the Move and Fixate centres to be greatest when untrained because NT participants do not know where to move their eyes to locate the target –as far as they are aware it could be found in *any* of eight possible locations. Although the issue of time pressure within each trial is not so much of a concern here, as it was in Chapters II and III (all participants have 10s to respond and the NT group do so in less than a third of this time on average), one may think that the NT group are under increased pressure to deal with identifying the central letter response quickly because they potentially have eight target locations to examine. This could increase conflict between the Move and Fixate centres to a larger extent than when one target location is known in advance (as with the MT group). Hence, untrained participants may use peripheral vision to confirm their responses and help maintain accuracy.

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[3] The central letters are of sufficient size to be detectable via peripheral vision when fixating the target or distractor items; in accordance with what is known about cortical magnification scaling (Rovamo & Virsu, 1979; Tripathy & Cavanagh, 2002). Personal introspection on piloting the task myself, confirms that it is certainly possible to see enough of the central letter even when fixating an item in the circular array around it. Moreover, using peripheral vision in this way would only be for purposes of checking, not identification from scratch, which would probably be harder at this eccentricity (Rayner & Pollatsek, 1989).

Alternatively, a larger period of time elapses for the NT group in between first completing the letter discrimination at the start of a trial and responding at the end of the trial. During this time distractor items are inspected. It is entirely possible therefore, that NT participants have a degraded memory representation for the central letter judgement when it comes to responding at the end of the trial. This may not be due to Move–Fixate competition, but may still lead this group to rely on peripheral vision to look back at the centre prior to responding. Removing the central letter from the display following the initial central gaze duration will also have the advantage of addressing these issues.

Other questions which arise as a result of restricting the length of time the central letter is displayed for revolve around whether participants can utilise voluntary control over eye movements (level 5 of Findlay & Walker's model). Participants were divided into training groups in Experiment 6 as previously, using the same design structure, and the duration the central letter remained on the screen was equal to the mean initial central gaze duration in a given block taken from Experiment 5 (i.e. baseline, feedback, or no feedback, for each training group. Note that these values were not statistically different). Given this artificially imposed time limit, maybe participants can suppress the natural inclination to *move* their eyes at the beginning of a trial in a similar way as the voluntary control over eye movements described by Mosimann (2004, reviewed at the beginning of this chapter). For the MT group such a strategy might help maintain accuracy by making the initial processing of the central letter more efficient. However, one might also expect this to impede the ability to use the MT sequence (recall that Mosimann observed such a trade-off; saccade accuracy decreasing when eye movements were intentionally withheld).

Precluding the possible outcomes above, the main prediction of Experiment 6, as stated at the beginning of this section, is that accuracy will be lower for the MT group when feedback is provided, because they will be unable to re-fixate the central letter at the end of each trial, as it seems they needed to in Experiment 5. However I should draw to the reader's attention at this point that although eye movements were recorded in this experiment, tracker loss meant that insufficient data remained for purposes of statistical analysis. However, eye movement data has less bearing on the main predictions of this experiment and the rationale behind them. The major prediction is a reduction in *manual response accuracy* for the MT group (in the feedback condition). The subsidiary predictions can likewise be evaluated with reference to either manual accuracy or reaction times. For instance, if the NT group are worse because they cannot look back at the central letter using peripheral vision, their accuracy should be affected too; or, if the MT group purposefully try to extract information from the central letter more effectively, and this hinders their ability to utilise the training sequence, their reaction time training effect should be smaller than we previously observed. Because the initial central gaze duration is fixed at the value attained in the last experiment, it cannot increase; likewise, re-fixations at the end of a trial cannot occur. Therefore, although there were an unsatisfactory number of cases where insufficient data points contributed to the cell means for the eye movement measures (applying the inclusion criteria of Exp. 5), it was known in advance that the manual response data was more central to the results. Hence, the omission of eye movement recordings does not necessarily undermine the findings of the present experiment –we are not so concerned about eye tracking data here anyway.

4.2.1. Method

Participants

Thirty new participants (with a mean age of 24 years, range 18-42; 19 female) were recruited from the University of Nottingham's student population. All participants reported normal or corrected-to-normal vision.

Stimuli & Apparatus

The same stimulus arrays were used in this experiment as in Experiment 5. The hardware, and set-up, was also identical to the previous study.

Design

The design used for this experiment was essentially the same as Experiment 5. There was a baseline Block, and the second Block was equally divided into counterbalanced FB and NFB conditions. The number of trials per block, and stimulus selection, was identical to the previous experiment. Again there were three Training groups, NT, MT, and BT, and Training was operationalised in the same way as before. All groups contained the same number of participants (N =10).

The major change in Experiment 6 was that the duration the central letter remained on the screen was manipulated. For each block (baseline, FB, and NFB) the central letter remained on the screen for the duration equal to the initial central gaze duration observed in that block in Experiment 5; these timings were also tailored to the training group in hand. For example, the initial central gaze duration of the BT group in the NFB condition of Experiment 5 was 471ms; therefore the central letter disappeared off the screen after 471ms for the BT group in the NFB condition of the present experiment. The offset of the central letter was determined in this way for all groups across each block with respect to the initial central gaze durations from

Experiment 5 (see Table 4.2). Although new participants were tested in the present experiment, because there were no significant differences in *any* of the measures of initial letter inspection in the previous experiment (baseline included), the method employed is considered a reasonable approximation of the time needed to extract the correct information for the letter discrimination judgement when the trial commences.

Procedure

The procedure was also the same in Experiment 6 as in Experiment 5, with one notable addition. As the task is more difficult in the present experiment (because the central letter disappears) participants were allowed more practice initially. Sixty four practice trials in which the task was identical to the baseline block of Experiment 5 were completed first. As well as this 'pre-baseline practice' there were also thirty trials practice before block 1 and block 2, as in Experiment 5, in which stimulus presentation was identical to the block which would follow (i.e. with the central letter disappearing). Trained participants were to use their respective training strategy(ies) in the practice block preceding block 2 trials. As before, training was provided via on screen instructions which the experimenter further clarified if necessary. For block 2, participants were always informed whether the trials they were about to complete would contain feedback or not.

The extra practice, identical to Experiment 5 (i.e. without the central letter disappearing), was included at the beginning of the experiment to afford participants sufficient time to become accustomed to the harder task in a step-by-step manner; in turn this should help ensure participants carry out the task in the same way as previously. I did not want people to develop strategies to deal with the fact the central letter disappears after a predictable time. Giving participants a fairly lengthy practice block right at the start of the experiment in which the central letter remains on the screen should promote task completion comparable to Experiment 5.

4.2.2. Results

Reaction Times

Practice trials, catch trials and anticipatory responses (RT <200ms) were removed before analysis for all analyses described. RT's were measured from the start of the trial, i.e. including the period before the central letter disappeared. Although the data collected was analysed in terms of difference scores, summary statistics showing the means in each condition are given below (Table 4.3).

The 3x2 ANOVA (three levels of Training; two levels of Feedback) conducted with the RT difference scores revealed no significant differences below p value 0.05. However, the simple main effect of training approached significance in the direction previously reported ($F(2, 27) = 2.8$, *MSE* = 109225, $p = 0.08$), suggesting a larger reduction in RT for the trained groups (MT $\overline{x_{Block_2} - x_{Block_1}}$ = -497ms, S.E.M = 104.5; BT $\overline{x_{Block_2} - x_{Block_1}}$ = -513ms, S.E.M = 104.5) compared to the NT group ($\overline{x_{Block_2} - x_{Block_1}}$ = -204ms, S.E.M = 104.5). No baseline differences were observed between groups for either of the manual response dependent variables analysed in this experiment (RTs or Accuracy).

One potential reason that the robust effect of directing training at the Move centre we have observed thus far did not lead to such large decreases in RT in the present experiment, may be because participants intentionally concentrate their efforts towards the letter discrimination judgement at the start of the trial, with the knowledge that it will shortly disappear and no longer be available. This may recruit resources subserved by the Fixate centre, consequently suppressing Move centre activity, and therefore the ability to benefit from MT. Such an outcome was mentioned when introducing this experiment. However, it is unlikely that this interpretation is correct if one considers that all groups were allowed substantial practice beforehand in the pre-baseline practice block (sixty four trials). In fact, the average RT across groups for this initial practice period (3133ms) was very similar to baseline performance in Experiment 5 (see table 4.1), and the ensuing reaction time decrease to the baseline block of the current experiment (513ms) was also comparable to the effect of practice alone reported in the last study (i.e. 412ms for the NT group). It is quite probable therefore that training directed at the Move centre provided less additional gain over the effects of practice already established, and that this is the reason for the diminution of the training effect for the MT [and BT] group.

Taking account of the above, the more direct comparison to examine whether participants in Experiment 6 have a diminished ability to benefit from MT (due to focusing more diligently on the central letter), is to compare their absolute RTs in block 2 to those of the MT group in Experiment 5. Two independent samples *t*-tests, the first comparing MT groups in the FB condition between experiments, the second comparing the same groups in the NFB condition, were carried out. Neither of these revealed significant differences (both p's > 0.05); if anything, the MT group of the present experiment were fastest (Exp 5: $\bar{x}_{FB}$ = 2434ms, $\bar{x}_{NFB}$ = 2524; Exp 6: $\bar{x}_{FB}$ = 2046ms, $\bar{x}_{NFB}$ = 2084ms), lending support to the alternative explanation that the extra practice at the start reduces RTs.

Accuracy

The difference score analysis revealed no significant effects with the accuracy data in this study. Accuracy remained high ($\bar{x}$ = 90% correct overall, Std Dev = 7.7), but as the main prediction centred around a decline in accuracy, performance for the experiment in hand was compared to that of Experiment 5. It is possible that all groups' accuracy dropped off in Experiment 6, and this would not be revealed in the omnibus statistics confined to this experiment. A 2x3x3 mixed factorial ANOVA, with two levels of 'Experiment' (Exp 5 vs. Exp 6), three levels of Training (NT, MT, BT) and three levels of Block (baseline, FB, NFB), was conducted to compare the absolute accuracy scores between experiments. This analysis revealed a significant main effect of Block (epsilon corrected F [1.8, 124] due to violation of the sphericity assumption = 5.7, *MSE* = 24.3, p = 0.006). This reflects the increases from baseline ($\bar{x}$ = 90.3%) to block 2 ($\bar{x}$ = 92.3) overall. (Helmert planned-contrasts showed that the FB and NFB sections of block 2 did not differ: $p > 0.05$). There was also a significant main effect of Experiment ($F(1,62) = 5.2$, *MSE* = 27.9, p = 0.026), reflecting superior performance in Experiment 5 ($\bar{x}$ = 93.1) compared to Experiment 6 ($\bar{x}$ = 90.2). There were no other significant effects with this analysis.

Training group		Block 1 (baseline)	Block 2 Feedback	Block 2 No Feedback
NT	Reaction Time	2524	2212	2428
		123	*147*	*210*
	Accuracy	89	90	92
		3.1	*2.4*	*2.3*
MT	Reaction Time	2562	2045	2084
		248	228	175
	Accuracy	87	88	92
		3.0	*2.5*	*2.6*
BT	Reaction Time	2771	2253	2264
		59	*104*	*142*
	Accuracy	90	92	92
		2.2	*1.9*	*2.0*

Table 4.3. Mean reaction times (ms) and accuracy (%) for each group in each condition. Standard errors are italicised.

4.2.3. Discussion

Why does accuracy decrease in the present experiment compared to when the central letter remains constantly visible? An accuracy decrease was predicted for the MT group, but it appears that the performance of all groups suffers slightly when the central letter is removed from view after the initial period of inspection. Granted, the task is much harder because the processing of the central letter is not self-paced, but perhaps there is some veracity in the peripheral vision account. Maybe all groups needed to re-check the central letter before responding in Experiment 5, but the NT and BT groups could rely more upon peripheral vision. The fact that the letter disappeared in Experiment 6 would exclude the possibilities of both overt re-inspections *and* covert re-checking via peripheral vision for the purposes of maintaining accuracy, hence, providing one explanation why we observe a general decrease in the present experiment.

In contrast, the lack of between groups differences in accuracy may be less to do with peripheral vision and more to do with participants adapting to deal with a task which is generally more challenging. Perhaps participants can override the proclivity to direct attention away from the central letter to locate the peripheral target, and this offsets what would otherwise be a greater reduction in accuracy in the present experiment. This may be particularly true of the MT group. We have already discussed previous reports of such voluntary control over attention capture, but one finding in particular is yet to be mentioned, and may contribute to understanding behaviour in the present task. Coeckelbergh, Cornelissen, Brouwer, & Kooijman (2002) studied individuals with a central scotoma (visual field defect) arising as a consequence of ocular pathology (such as glaucoma), and found, paradoxically, that fewer return fixations were exhibited in Landolt –C visual search the *greater* the degree of impairment. The authors interpret their findings with reference to Findlay & Walker's (1999) model, arguing that with clinical cases of central scotoma a compensatory strategy is adopted where participants… "consciously suppressed the tendency to initiate a saccade before the central information has been acquired. The cognitive control of subjects to voluntarily suppress saccades and maintain fixation is described in the model by Findlay and Walker…" (Coeckelbergh et al., 2002, p. 676). They contrast this result with the observation that *simulated* scotoma leads to a greater number of return fixations in healthy volunteers, as ordinarily one would expect. Perhaps the visual scanning behaviour of the MT group in Experiment 5 may be likened to this artificial scotoma group; however, in Experiment 6, where the need to identify the central letter response quickly is paramount to accuracy, participants may be able to implement an overriding supervisory mechanism, preventing disengagement from the letter before it is fully processed. Such a strategy would parallel the interpretation offered by

Coeckelbergh et al. (2002) for the oculomotor behaviour of their clinical sample. *Temporal Preparation* in Findlay & Walker's model, moreover, would further support such a strategy in my task, as participants become accustomed to the predictable timing of the offset of the letter.

One final possibility to explain the results obtained thus far in this chapter is now considered, before moving on. Perhaps none of the above explanations (involving peripheral vision and voluntary inhibition of eye movements to peripheral array items) apply, and the finding of longer re-inspection durations for the MT group in Experiment 5 does not reflect premature disengagement from the central letter at the start of the trial. Maybe MT participants do not *need* to look back, but do so just because they can; when they are prevented from re-fixating (as in Experiment 6) their accuracy is therefore unaffected relative to the NT and BT groups. If one favours this argument, I would still point out that if the longer time spent re-inspecting the central letter is redundant, this is still wasted resources, and could therefore still reflect detection failures for which training that promotes activity in the Move centre is accountable.

The final experiment of this chapter is set up to disentangle the explanations offered here. The basic task remains the same, but with the new version the entire display is gaze-contingent –items are only visible within a spatially restricted window around the point of fixation.

4.3. Experiment 7 - Training eye movements with a gaze-contingent display

In Experiment 7 participants completed the same visual search-like task with the centrally located letter contained within the circular array of potential targets. However, while the basic task remains identical to the first experiment in this series

(Experiment 5), the presentation of the stimulus display differs. In Experiment 7 only items currently under inspection were visible; the rest of the display appeared to contain nothing –a blank white background –unless the location of a display item was fixated. A gaze-contingent moving window was thus tied to the point of fixation, constricting viewing to the current point of regard.

This method is often employed in the empirical study of eye movements in reading, and was coined the 'Moving Window' technique by Keith Rayner and colleagues (originally McConkie & Rayner, 1975). More recently the method has become popular in the visual search literature also, for the same reasons: it allows inferences to be made about the acquisition of information when peripheral vision is unavailable (Henderson & Castelhano, 2007), and more specifically, the influence of peripheral vision on fixational eye movements and the duration of inspections (van Diepen & d'Ydewalle, 2003). It provides an ideal methodology therefore for tackling the four outstanding issues which have been raised thus far:

1. *Peripheral Vision* – the possibility of the NT and BT groups re-checking the central letter via peripheral vision will again be eliminated, but with the moving window paradigm overt re-fixations can be made to re-check the central letter if this is necessary to maintain accuracy. An overall improvement in accuracy from the last experiment, to the levels first observed in Experiment 5, should therefore be associated with *all groups* making longer overt re-inspections when the display is gaze-contingent if the peripheral vision account is correct. This would support the conclusion that under normal viewing conditions the NT and BT groups can utilise peripheral vision to glimpse the central letter and confirm their responses, whereas the MT group alone require longer overt re-inspections, even when the central letter is visible in extra-foveal vision. Such a conclusion would be interpreted in the light of impoverished representations with increasing distance from the point of maximum

visual acuity, the fovea (Westheimer, 1965). Perhaps perception of the letters' basic features, distal from the fovea, is usually sufficient for the NT and BT groups. However, if Move training in isolation causes inadequate processing of the letter when it is first inspected, the MT group may always require the greater acuity afforded by longer *overt* re-inspections to apprehend the correct response properly.

2. *Voluntary Control* – the possibility of participants strategically adapting to process the central letter more effectively will be much reduced in Experiment 7 in comparison to Experiment 6. The task will again be self-paced, lessening likelihood of participants becoming more efficient at the letter discriminations by purposefully maintaining central fixation at the start of each trial. We can be more confident therefore that if participants do not re-visit the central letter prior to a response, that this does not reflect voluntary concentrating of efforts to apprehend the letter in the first pass.

3. *Whether the MT group really needed to look back for longer in Experiment 5* – re-inspections can be made, *if they are necessary*, when the display is gaze contingent. If the extended re-inspection durations of the MT group fails to replicate then it is more likely that the combination of top down training directed at the Move centre, *and* the peripheral array target being visible, is necessary to bring about premature disengagement from the central letter before it is fully processed. This will shed further light on the interplay between top down and bottom up factors when training eye movements, consistent with the aims of this thesis (i.e. any Move centre activity should be completely top down in the present experiment).

4. *Covert attention shifts when initially processing the central letter* – this final issue was raised when discussing the results of Experiment 5 (section 4.1.3, p.154), and very much relates to the questions posed in the paragraph directly above. So far, the propositions concerning peripheral vision exclusively refer to re-checking the central

letter when fixated on an item in the periphery (most commonly this would presumably be the target number just before a response is made). However, a similar logic can also be applied to the initial central gaze durations. Given that initial central gaze durations were not statistically different in Experiment 5, one suggestion for the longer re-inspection durations was that MT participants made a premature shift of covert attention away from the central letter at the start of the trial. This draws upon awareness of the target number in peripheral vision. However, because the question of whether the timing of covert shifts can vary remains controversial in the literature, an alternative explanation was also proposed. This explanation drew upon results from the previous chapter, the argument being that training directed at the Move centre may reduce the efficiency of fixations contained within the initial central gaze duration, in a similar way as proposed with the extended gaze durations of the MT group in Experiment 4. It was suggested that with the present experimental paradigm, where two locations compete for attentional resources within the same trial, the MT group are drawn away from the central letter too soon, without spending the extra time needed to offset this reduced effectiveness of each fixation caused by Move–Fixate competition. In this case it is unnecessary to allude to differences in the timing of covert attentional shifts.

One can address these two alternatives more directly with the gaze-contingent display of the present experiment. If the initial central gaze durations of the MT group increase relative to the NT and BT groups, but there is no difference in the re-inspection durations between groups, then this would add weight to the latter argument that MT reduces the efficiency of fixations contained within the initial central gaze duration. The fact that the peripheral array, and therefore the target number, is not visible to participants in Experiment 7 when they are fixating the letter at the start of each trial may reduce the 'pull' of the Move centre towards the target's location when directed in MT. Nevertheless, the influence MT exerts may still cause processing to be less than optimal during this period, but in the absence of a visible saccade target the result is complete classification of the central letter, albeit in a protracted time-frame. Hence, extended initial central gaze durations, unaccompanied by longer re-inspection durations. On the other hand, if the initial central gaze durations do not differ between groups, and are comparable to Experiment 5, one will have a clearer idea about the validity of the covert attention hypothesis depending on the re-inspection durations. To replicate increased re-inspection durations of the MT group in this scenario would suggest that top down training of the Move centre is sufficient to hinder the processing of the central letter. And given that covert shifts of attention are less likely in the absence of a visible saccade target, the supposition would be the same as above: that MT causes information acquisition during fixations to be less efficient, and eye movements to be directed too soon. However, similar initial central gaze durations, both between groups, and in comparison to Experiment 5, *unaccompanied* by longer re-inspection durations for the MT group, would suggest that when the target number is not concurrently visible, premature covert shifts of attention do not occur; but they *do* when the target number *is* visible (i.e. as in Experiment 5). Ergo, top down training of the Move centre would be necessary but not sufficient to cause detrimental processing of the central letter. If these results are borne out this would indicate that only when bottom up stimulus properties (the target number being visible during the initial central gaze duration) *and* top down training (the MT sequence) influence the Move centre in unison, do we observe the performance detriment seen in Experiment 5. (Each of these predictions for the eye movement data rests on manual response accuracy being high, and equal between training groups).

Finally, a minor amendment was made to the design of Experiment 7 to help understand the results with respect to the feedback manipulation. In the NFB section of block 2 either a green or purple mask followed each trial, the colour being determined at random irrespective of the response, such that feedback was non-informative. Veridical feedback in the baseline block, and the FB section of block 2, was the same as before, with a blue (correct) and red (incorrect) mask following responses ('time-outs' were again considered incorrect). The rationale behind the adjustment was that if the feedback mask causes a processing bottleneck for the MT group, as suggested when discussing Experiment 5 (section 4.1.3), and this is purely to do with the disruptive influence of the mask per se, the effect should remain the same with equiluminant non-informative feedback. If, however, the effect is more related to the evaluative nature of error monitoring with veridical feedback, the presentation of a non-informative mask should have little impact, and produce results which mirror the NFB condition of Experiment 5. Of course, these predictions depend in part on the validity of the earlier hypotheses. However, the FB condition remains the same, and the assumption is that non-informative feedback will either be disruptive in the same way as informative feedback seemed to be, or have no effect.

4.3.1. Method

Participants

Thirty six new participants (with a mean age of 22 years, range 18-39; 21 female) were recruited from the University of Nottingham's student population. All participants reported normal or corrected-to-normal vision.

Stimuli & Apparatus

The same stimuli were used in this experiment as previously. A different eye tracker was used however, an Eyelink II (SR Research), because it has fully integrated software and hardware capabilities to design and run gaze contingent experiments. The set-up was therefore slightly different: participants were seated 60cm away from a 20″ ViewSonic monitor, and their eye movements were recorded with two small head-mounted cameras which sampled pupil location at 500Hz. The slight change in viewing distance and screen dimensions meant that the display now subtended 37°x28° visual angle, and therefore that the stimulus array appeared a little larger (by a factor of approximately 1.2) than the last two experiments. The same pixel resolution was used (1024x768). The Eyelink II is a video-based system which identifies fixations and saccades using thresholds for displacement, velocity, and acceleration, which are 0.10°, 30°/s, and $8000°/S^2$, respectively as standard. Viewing was stabilised with a chin-rest, as before.

Design

The experiment was divided into two blocks of 192 experimental trials, 50% longer than before in total. Baseline performance was assessed in Block 1 and Training was provided in between Block 1 and 2, as previously. Again the sequence of target location was pre-determined throughout, but stimulus selection was otherwise quasi-random, the only difference from the last two experiments being that catch trials (where the target is an odd number) were presented with 50% probability in each block. There were several reasons for the adjustment in block length and number of catch trials. Primarily, increasing the number of catch trials indirectly reduces likelihood the central letter response will be classified properly at the start of the trial (because participants have simply to press the same key irrespective of which letter was presented). In so doing this should exacerbate any detrimental effects associated with training directed at the Move centre. Moreover, because the number of trials per block is larger, a greater number of experimental trials still contribute to the subject means once catch trials are excluded from the statistical analysis (192, versus $170.\dot{6}$ in Exp 5 & 6[4]). This will also have the advantage of marginally increasing statistical power. And a final point about the increased length of the experiment is that, although there has been little sign of either explicit or implicit learning of the training strategies so far in this thesis (one participant only correctly guessed MT sequences back in Experiment 2), it is possible that with greater exposure participants will guess the rules which govern stimulus presentation here. If so, it may be interesting to identify the point at which learning occurs when untrained. I will comment upon this, however, as it is not central to the main research questions, coverage will be brief.

The same three training groups were used (NT, MT, and BT), each having the same sample size (*N* = 12). In a small adjustment, trial selection for subjects was matched between groups: the first subject in the NT group underwent the same order of stimulus presentation as the first subjects in the MT and BT groups, and so on for the second, third, and fourth subjects... etc. Trial selection was randomised, but there were twelve randomised orders of stimulus selection for an entire run of the experiment for one subject. This provides a higher degree of control because each trained subject was paired with a control comparison subject in the NT group, who was exposed to exactly the same presentation order of stimulus arrays.

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[4] Because the number of catch trials was probabilistically determined in the last two experiments (occurring with $33.\dot{3}$ % probability), there were $85.\dot{3}$ on average out of 256; therefore $170.\dot{6}$ were not catch trials and required a response discrimination based on the central letter.

Feedback was again manipulated as a within groups factor, block 2 being equally divided into FB and NFB sections, counterbalanced across subjects. During block 1, and the FB section of block 2, a transient blue (correct) or red (incorrect) mask followed responses, just as before ('time-outs' were considered incorrect). However, the NFB condition differed from Experiments 5 and 6. To try and determine whether the effects of feedback reported in Experiment 5 (specifically, longer re-fixation durations for the MT group when feedback was provided) were because of the flash of a transient mask per se, or because of the mask being informative as to the accuracy of responses, non-informative feedback was presented in the NFB condition of this experiment. Either a purple or green mask followed each trial, the colour being determined at random irrespective of the response (previously, a grey mask, barely distinguishable from the white background of the stimulus array, was always presented in the NFB condition). In accordance with the rationale for this change an effort was made to ensure all feedback masks were equiluminant. The luminance of the blue, red, purple, and green masks was 32, 21, 26, and 31cd/m^2 respectively, adjusted using Photoshop software.

The same eye movement measures were collected as in Experiment 5. However, interest areas were defined with greater precision. Fixations contained within a circular interest area of radius 1° visual angle, centred on, and encompassing the central letter, were classified as being for the purpose of letter processing. An Elliptical interest area (vertex 1°, co-vertex 1.3°, visual angle) was centred on each peripheral character, encompassing it in order that target fixations could be identified.

A square gaze-contingent moving-window of area 161 pixels^2 was used. The dimensions were chosen based on the size of the central letter interest area in Experiment 5, and to ensure that only one item in the stimulus array was visible at a time. The moving window was tied to the point of fixation such that items in the stimulus array must be fixated to be viewed. The area outside the moving window was blank (white), just as the background of the stimulus array. The decision was made not to use placeholders for the peripheral shapes because one of the motivations for the current experiment was to assess eye *movement* training which is purely top-down (i.e. in the absence of bottom up stimulus properties). This should shed further light on the upper levels of Findlay & Walker's (1999) model, the WHERE pathway in particular.

Accuracy and reaction time data were collected as before, and all dependent variables are analysed in the same way as the last two experiments of this chapter.

Procedure

The procedure was virtually the same as in Experiments 5, with a few minor exceptions.

The eye to be tracked following calibration was selected by the Eyelink system based on the lowest mean spatial error (if necessary the calibration process was repeated until the operating PC deemed spatial accuracy to be "Good" for the selected eye). To help maintain this level of accuracy a drift correct dot appeared centrally in-between trials; participants confirmed fixation of the dot by pressing the spacebar before they could move on.

Different keyboard buttons were used for responding. 'O' and 'P' are adjacent on the keyboard and were designated for left and right responses respectively; the 'Z' key was designated for catch trials.

The initial practice before the baseline block, and practice before block 2, was twenty trials long, whereas previously practice was thirty trials in length. This was a purely pragmatic change due to the increased length of the experiment overall.

The experimenter guided participants through the first few practice trials if required, so that they could become accustomed to the gaze contingent display.

4.3.2. Results

Reaction Times

Practice trials, catch trials and anticipatory responses (RT <200ms) were removed before analysis for all analyses described. As has been the case throughout, the amount of anticipatory responses was negligible (in this experiment only 1 trial out of 13,824 experimental trials). As previously, RT's to correct answers were collated, and the difference scores were analysed (but see Table 4.4 for the overall means in each condition).

A significant main effect of training was observed (F (2, 33) = 32.4, *MSE* = 285241, p < 0.001), reflecting the greater improvement in RT for the trained groups (MT $\overline{x_{Block_2} - x_{Block_1}}$ = -1793ms, S.E.M = 109.0; BT $\overline{x_{Block_2} - x_{Block_1}}$ = -1704ms, S.E.M = 109.0) compared to the NT group ($\overline{x_{Block_2} - x_{Block_1}}$ = -676ms, S.E.M = 109.0). Post-hoc comparisons with Tukey's HSD confirmed that while the trained groups both differed significantly from the NT group (p's <0.001), the MT and BT group did not differ from each other (p = 0.834). There was no main effect of feedback, and feedback did not interact with training.

No baseline differences were observed between groups for RT's, or any of the measures reported henceforth.

Accuracy

No significant main effects were found in the accuracy analysis, neither did the factors interact. Accuracy was high however ($\bar{x}$ = 93% correct overall, Std Dev = 8.8). See Table 4.4 for overall means in each condition.

Previously (Exp 6 results) the absolute accuracy scores were compared between experiments and it was found that when the central letter disappeared accuracy declined slightly. One might therefore expect accuracy to increase to normal levels again here because the task is once more self-paced, and participants are free to look back at the letter if they need to (although an overt eye movement would have to be made, there could be no reliance on peripheral vision). The 3x3x3 ANOVA conducted to assess whether accuracy is only lower in Experiment 6 (three levels of Experiment: Exp 5 vs. Exp 6 vs. Exp 7; three levels of Training: NT, MT, BT; three levels of Block: baseline, FB, NFB) revealed a significant main effect of block only ($F(2, 190) = 12.0$, *MSE* = 19.3, $p < 0.001$). Statistically therefore this omnibus analysis reveals no differences in accuracy between experiments. The only main effect (Block) reflects the general improvement from baseline ($\bar{x}$ = 90.5) to block 2 ($\bar{x}$ = 92.9) irrespective of training group, as previously observed. Helmert planned-contrasts showed that the FB and NFB sections of block 2 also differed, albeit marginally ($F(1, 95) = 4.2$, *MSE* = 33.1, $p = 0.043$). Perhaps the slightly higher accuracy in the NFB condition ($\bar{x}_{FB}$ = 92.3; $\bar{x}_{NFB}$ = 93.4) over all three experiments indicates that veridical feedback is indeed disruptive, as suggested when discussing the results of Experiment 5 (section 4.1.3); or perhaps the lack of feedback simply makes people more cautious about responding correctly. This result should be interpreted with caution however, not only because it is a marginal effect, but also because each experiment was quite different, the present experiment in particular as the NFB condition contained equiluminant non-informative masks.

The fact there was no overall difference in accuracy between experiments here does not allow one to conclude with certainty that accuracy dips when the central letter disappears (Exp 6), but returns to normal levels (Exp5) when the letter can be re-visited in a gaze contingent display (Exp 7). However, I would point out that overall accuracy in Experiments 5 and 7 ($\bar{x}$ = 93.1; $\bar{x}$ = 92.9, respectively) was slightly higher than in Experiment 6 ($\bar{x}$ = 90.2), but it appears that the difference between experiments observed previously is swamped with this larger data set (recall there was a significant decline in accuracy when the letter disappeared in Exp. 6 compared to when it did not in Exp. 5, reported in when these two experiments only were compared the previous results section: section 4.2.2).

Training group		Block 1 (baseline)	Block 2	
			Feedback	No Feedback
NT	Reaction Time	3984	3267	3350
		143	*127*	*128*
	Accuracy	89	91	92
		4.0	*3.2*	*4.4*
MT	Reaction Time	4138	2341	2350
		179	*209*	*224*
	Accuracy	91.3	94.0	94.6
		1.5	*1.7*	*1.7*
BT	Reaction Time	4049	2333	2357
		119	*146*	*129*
	Accuracy	92.1	95.9	95.8
		1.7	*1.3*	*1.4*

Table 4.4. Mean reaction times (ms) and accuracy (%) for each group in each condition. Standard errors are italicised.

Eye Movement Recordings

In addition to the filtering applied to the manual response data, trials in which the number target was not fixated, and in which the initial central gaze duration was less than 50ms were also removed before analysis of the eye movement data, in accordance with the exclusions applied in Experiment 5. There were so few trials in which the central letter was not fixated within 1s (0.2%), that it was viewed as unnecessary to apply any filtering to account for participants searching the peripheral array first. Following these exclusions eye movements were collated for correct answers, and an average of 51 trials contributed to participants' cell means for each condition. No participant was removed for excessive loss of eye movement data due to calibration difficulties etc. The eye movement measures were also analysed in terms of difference scores, but the absolute means in each condition are given in Table 4.5, below.

Training group	Eye movement statistic	Block 1 (baseline)	Block 2	
			Feedback	No Feedback
NT	Number of fixations per trial	12.9	11.3	11.3
		0.4	*0.5*	*0.3*
	Time to first target fixation	2836	2357	2457
		101	*61*	*90*
	Initial central gaze duration	513	403	465
		51	*29*	*48*
	Re-inspection duration	30	43	42
		12	*24*	*16*
	Number of re-fixations per trial	0.1	0.1	0.2
		0.0	*0.1*	*0.1*
MT	Number of fixations per trial	13.3	6.9	7.1
		0.4	*0.6*	*0.8*
	Time to first target fixation	2931	1145	1094
		91	*100*	*124*
	Initial central gaze duration	446	429	444
		28	*41*	*28*
	Re-inspection duration	96	148	150
		34	*46*	*45*
	Number of re-fixations per trial	0.4	0.5	0.6
		0.1	*0.2*	*0.2*
BT	Number of fixations per trial	13.1	6.5	6.7
		0.4	*0.5*	*0.4*
	Time to first target fixation	2982	1299	1289
		104	*120*	*100*
	Initial central gaze duration	558	595	563
		36	*58*	*54*
	Re-inspection duration	75	99	127
		14	*38*	*42*
	Number of re-fixations per trial	0.2	0.3	0.4
		0.1	*0.1*	*0.2*

Table 4.5. Summary statistics for the measures of eye movements taken (timings in ms). Means are shown for each group in each condition with standard errors italicised

Overall visual search performance

As before, the average number of fixations per trial were extracted from the data set and analysed to assess search efficiency. The relative changes from baseline within these data showed a significant main effect of training only (F (2, 33) = 43.0, *MSE* = 4.3, p <0.001), highlighting that the trained groups (MT $\overline{x_{Block_2} - x_{Block_1}}$ = -6.3, S.E.M = 0.4; BT $\overline{x_{Block_2} - x_{Block_1}}$ = -6.6, S.E.M = 0.4) make less fixations following training than the reduction owing to practice alone (NT $\overline{x_{Block_2} - x_{Block_1}}$ = -1.6, S.E.M = 0.4). Tukey HSD Post-hoc comparisons confirmed these differences (NT vs. MT, BT: p <0.001; MT vs. BT: p = 0.92). The effect appears to be stronger here than with this measure in Experiment 5, and this is probably because although the number of fixations made per trial following training was roughly the same in both experiments (see Table 4.2 & 4.5), more fixations were made at baseline by all groups with the gaze contingent display (Exp 5 $\bar{x}_{baseline}$ = 9.7; Exp 7 $\bar{x}_{baseline}$ = 13.1), therefore the reduction afforded by training is larger. A slight increase in number of fixations at baseline is not surprising with the present experiment since the peripheral array must be searched serially for the target, the eyes cannot be guided to it using peripheral vision.

Time to first target fixation was again drawn from the eye movement records to further evaluate visual search performance. The difference score analysis for this measure revealed a significant main effect of training only (F (2, 33) = 94.6, *MSE* = 148466, p <0.001), with the trained groups (MT $\overline{x_{Block_2} - x_{Block_1}}$ = -1811ms, S.E.M = 78.7; BT $\overline{x_{Block_2} - x_{Block_1}}$ = -1688ms, S.E.M = 78.7) improving more than the NT group ($\overline{x_{Block_2} - x_{Block_1}}$ = -429ms, S.E.M = 78.7). Post-hoc comparisons with Tukey's HSD revealed that both of the trained groups showed significantly greater improvements in visual search performance than the NT group (both p's <0.001). The MT and BT groups did not differ (p = 0.52). We have a very similar pattern to Experiment 5 here, with RT's and oculomotor measures demonstrating the enhanced search efficiency of the trained groups.

Eye movement patterns

Previously I looked at 'visual scanning behaviour' by plotting typical eye fixation sequences within a trial for example participants (Fig. 4.2). Whilst providing a good illustration of how people tackled the task when trained and untrained, it is not possible to generalise these particular eye movement patterns because only the data of selected participants in selected trials is displayed. It must be added, however, that these patterns *were* quite typical, but in order assess some aspects of their generality more rigorously, this sub-section evaluates eye movement patterns in aggregated fixation sequences across all observers in a group.

Fig. 4.5 shows radial histograms indicating the probability of all first, second, and third fixations deviating towards each of the eight potential target locations. Fixation locations were normalised relative to the target, such that Location 1 (i.e. 12 o'clock) is always the target position. It would be expected that the first fixation should usually be on the central letter, therefore should show little selective deviation towards any of the potential target locations; subsequent fixations should be more likely to deviate towards the 12 o'clock position for the trained groups however, since they know where the target will be. Principally this approach helps answer three questions with greater confidence: (i) Are there any general trends in the first phase of scanning, and do these differ between groups? (ii) Is there any sign of implicit learning of the predictable sequence of target presentation in the NT group? If so, once the central letter has been processed, fixations should not be evenly distributed, but there should be a tendency for the distribution to be skewed towards the 12 o'clock position when untrained. (iii) Do the trained groups go straight to the target once they have first dealt with the central letter, or do they use the previous target location as a place holder, fixating this first before moving their eyes to the target location of the trial in hand? I commented that this strategy was sometimes used in the results of Experiment 5 (section 4.1.2: 'visual scanning behaviour').

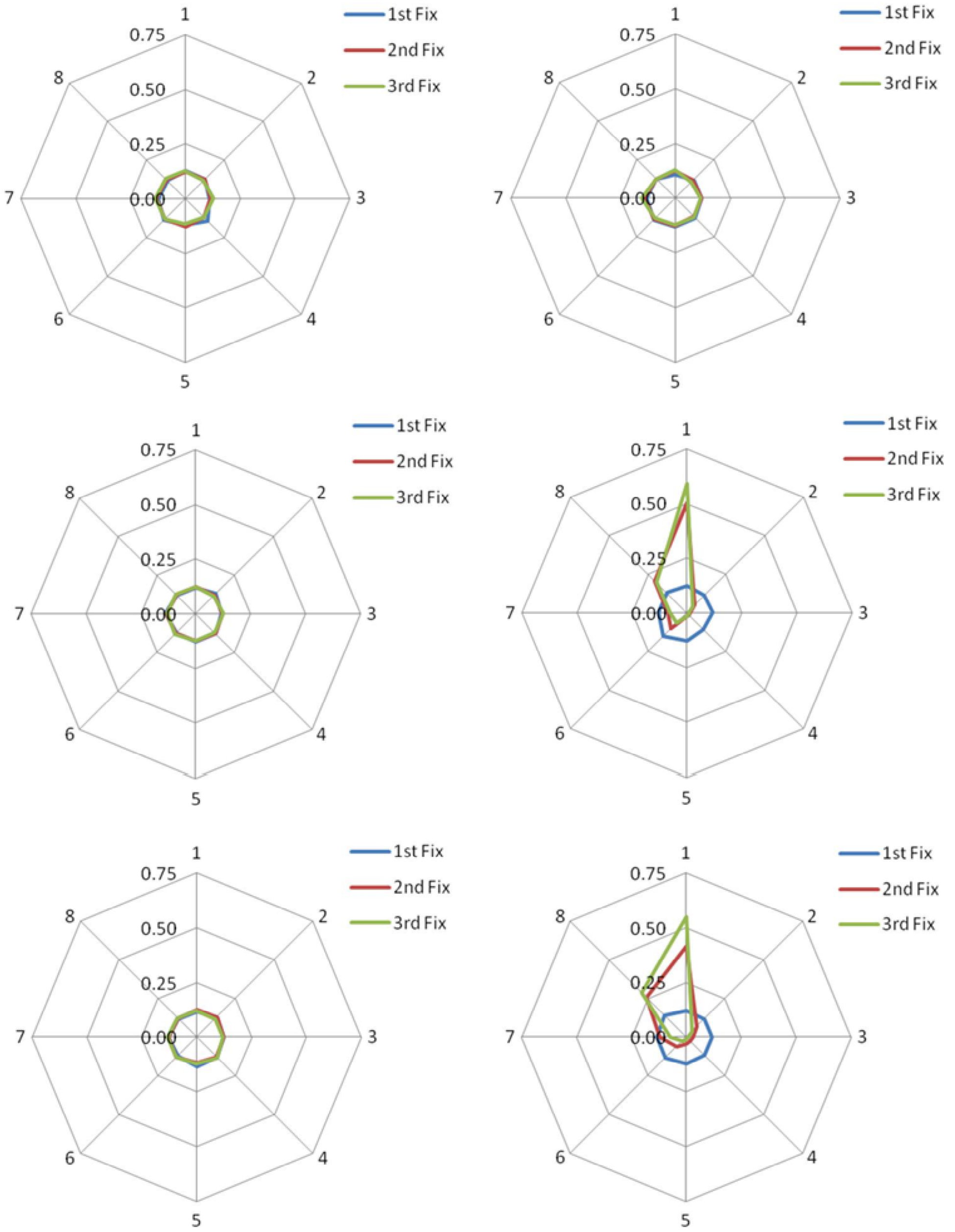

Fig. 4.5. Radial histograms with fixation probability (*y* axis) normalised around the target in reference position 1 (12 o'clock). In a given trial if the target was actually in position 4, for example, the angular distance of all fixations from north would have 135° subtracted, thereby normalising fixations relative to the target in the 12 0'clock position. Regions 22.5° (of a total 360 °) either side of the spokes intersecting each position were used to calculate fixation location. The probability of 1st, 2nd, and 3rd fixations occurring in each position (perimeter *x* axis) is plotted for the NT group (top row), MT group (middle row) and BT group (bottom row), at baseline (left column), and in block 2 (right column).

It appears from Fig. 4.5 that in the absence of training there is no bias in the first three fixations, all locations being fixated with roughly equal probability at baseline, and in block 2 for the NT group. Neither does there appear to be any sign of learning the experiment's contingencies when untrained, the distribution being even throughout for the NT group, and at baseline for the trained groups. This concurs with the majority of participants verbal reports: one participant in the MT group noticed the pattern of target presentation right at the end of the baseline block, before they were informed of it, and one participant in the NT group commented that the target seemed to appear "in each of the four corners in turn", which is not quite right, but does demonstrate some awareness of the contingency. Other than these, participants seemed to have no explicit awareness of the predictable order of target presentation, just as no one explicitly reported guessing the experiments' contingencies in the two previous experiments. This section also provides good evidence that there was no *implicit* learning either.

One last point about the eye movement patterns reported above. It was suggested when covering Experiment 5 that trained participants may prefer to use the target location in the previous trial as a placeholder, making eye movements here first, before fixating the target for the trial in hand. There is evidence that participants are conservative in their target directed eye movements, second and third fixations of the MT and BT groups being skewed to the left of the actual target location; however, the strategy of fixating the location which contained the target in the previous trial then moving round to the actual target location is not a generalisable trend. Second and third fixations of the trained groups most commonly go straight to the target, with a slight bias to be one location back from this position.

Central letter processing: Initial central gaze duration

To see whether training exerts an influence over the processing of the central letter at the start of the trial, initial central gaze durations were analysed, as before. Again, there were not any significant differences with the measure, either between-groups, or within-groups. To check whether other measures of initial central letter processing yielded any effects, both the mean number of fixations contained within the initial central gaze duration, and their mean duration, were analysed as previously. This time there was an effect of Training, but only in the latter of these measures. Mean fixation durations for fixations comprising the initial central gaze duration increased significantly for the BT group ($\overline{x_{Block_2} - x_{Block_1}}$ = 46ms, S.E.M = 24.7) compared to the decrease seen in the NT group ($\overline{x_{Block_2} - x_{Block_1}}$ = -45ms, S.E.M = 24.7); F (2, 33) = 3.6, *MSE* = 14650, p =0.039. This was confirmed by Tukey HSD post-hoc contrasts (NT vs. BT, p =0.035). The relative change from baseline in the MT group fell between the values obtained for the other two groups ($\overline{x_{Block_2} - x_{Block_1}}$ = 19ms, S.E.M = 24.7), and did not differ from either (both p's >0.1). Overall means for this measure are given in Table 4.6.

This result was not expected, but may be accommodated if one assumes that BT participants can carry out the letter discrimination well enough following baseline, therefore show a cost in adapting to use the symmetry rule (A, T, M, and V are all symmetrical; L, F, K, and N are not). Several reasons make this explanation plausible, and could account for this contrasting result (combined training has so far always been the *most* beneficial, but here it leads to fixations which are unnecessarily extended in duration). First, participants have more time to learn the response associations for the different letters, since the baseline block is longer. Second, there is a lack of distraction from the peripheral array with the display being gaze contingent, and this could make processing the letter easier to become accustomed to. Third, and consolidating the first two points, several participants reported on debrief that they found the training directed towards the Fixate centre (used by the BT group) to be unhelpful as they had got used to the letter and response key pairings (no-one reported this previously; in the last two experiments the consensus upon debrief seemed to be that the symmetry strategy was helpful). Does this mean there is no advantage to combined Move and Fixate training on this occasion? It is necessary to refer to re-inspections of the central letter to answer this question. I turn to these data next.

	Block 1 (baseline)	**Block 2**	
		Feedback	**No Feedback**
NT	410 *31*	344 *19*	386 *31*
MT	368 *22*	376 *23*	398 *21*
BT	437 *31*	483 *30*	484 *44*

Table 4.6. Mean fixation durations for fixations contained within the initial central gaze duration (ms). Averages are shown for each group in each condition with standard errors italicised.

Re-Inspections of the central letter

Return fixations to the central letter (i.e. those that were not part of the initial central gaze duration) were analysed as in the same way as before, firstly by looking at re-inspection duration, and secondly the number of re-fixations. Unlike Experiment 5 there were no effects on re-inspection durations: the MT group did not look back for longer in any condition of the experiment, although this was the direction of the between group means (NT $\overline{x_{Block_2} - x_{Block_1}}$ = 12ms, S.E.M = 21.2; MT

$\overline{x_{Block_2} - x_{Block_1}}$ = 53ms, S.E.M = 21.2; BT $\overline{x_{Block_2} - x_{Block_1}}$ = 37ms, S.E.M = 37ms). There was a within groups effect of Feedback with the analysis for number of re-fixations (F (1, 33) = 4.4, *MSE* = 0.02, p =0.043). This shows that re-fixations were somewhat more numerous when veridical feedback was withheld and instead a non-informative coloured mask followed each trial ($\overline{x_{Block\ 2_{FB}} - x_{Block\ 1}}$ = 0.09, S.E.M = 0.04; $\overline{x_{Block\ 2_{NFB}} - x_{Block\ 1}}$ = 0.17, S.E.M = 0.06). The analysis of the number of re-fixations did not reveal any other significant effects. It appears that the transient flash of a coloured mask which has no bearing on the trial's accuracy gives rise to a slightly greater degree of caution in all groups, participants checking their responses by re-fixating the central letter more often irrespective of training. The irrelevant feedback masks used in the NFB condition of the present experiment may have a distracting effect over and above any interference which may be caused by the flash of an [informative] transient mask per se –maybe participants cannot ignore non-informative feedback masks and this disrupts their ability to respond fluently and with confidence. There is also the possibility however that participants were trying to read something into the random presentation of coloured masks, increasing the frequency of re-fixations in the NFB condition.

It may also be noticed also that we do not observe the overall reductions in number of re-fixations in this experiment that were seen in Experiment 5. This is not central to the main hypotheses but may reflect the increased length of Experiment 7; it is conceivable that participants show signs of a fatigue effect, re-visiting the central letter a little more than at baseline to help with responding correctly when concentration levels drop towards the end of the testing session.

Finally, it was commented at the end of the last section that the increased mean fixation durations of the BT group when initially processing the central letter at the start of the trial would be returned to in light of the re-inspection results, to address whether combined Move and Fixate training has any value in Experiment 7. It seems that it does not. The MT group do not need to re-inspect the central letter more regularly in the current experiment, as they did in Experiment 5 when the entire stimulus array was constantly visible. Therefore the symmetry rule employed by the BT group, in concert with Move training, serves no purpose. It does not make people faster or more accurate, as seen with the manual response data, nor does it offset incomplete processing of the central letter brought about by MT in isolation. In fact, it seems that participants are better able to learn the response and letter pairings when the display is gaze contingent, possibly because they not distracted by the peripheral characters in the circular array, and possibly because the baseline block is slightly longer in this experiment than previously. As a consequence, training directed at the Fixate centre is something of a hindrance in the present experiment. When the existing technique is sufficient and consolidated, trying to implement a new strategy increases fixation durations, and may therefore be likened to the evidence of top down control biasing the Fixate centre cited when introducing this chapter. On this occasion the effect is detrimental. In hindsight, different symmetrical and asymmetrical letters could have been used in block two. This would allow direct assessment of the above argument.

4.3.3. Discussion and Chapter Conclusions

A principal reason behind the current experiment was to shed light upon the role of peripheral vision in the results obtained in Experiments 5 and 6. On the one hand it is possible that the NT and BT groups relied upon peripheral vision to re-check the letter before responding in Experiment 5, and this is why all groups showed a slight decline in accuracy in Experiment 6 when the central letter was no longer available after the initial period of inspection (the argument being that MT participants need to make *overt* re-fixations more regularly, and this would lead to their accuracy reduction in Experiment 6 when the central letter disappeared). Alternatively peripheral vision could also be used to *at the start of the trial* when the central letter is being first inspected. In this respect one of the aims was to elucidate whether the results of Experiment 5 were owing to early covert attention shifts in the MT group. These two possibilities will be evaluated in turn.

Accuracy was not lower in the current experiment, as it was when the central letter disappeared in Experiment 6. Did accuracy reduce overall in Experiment 6 because the NT and BT groups could not rely upon peripheral vision to look back at the centre (and the MT group could not make overt re-fixations)? If so, with the gaze contingent display (i.e. no peripheral vision) one would expect re-fixations to be more numerous irrespective of training group, accounting for the virtually identical accuracy scores between Experiments 5 and 7. This was not the case. It can be seen in Table 4.2 and 4.5 that the number of re-fixations was actually fewer in the present experiment, overall participants re-fixating the letter on three out of every ten trials compared to roughly eight in ten with Experiment 5[5]. As well as the slightly different set-up of the eye tracker, this may also be because participants learn the letter responses more effectively, the baseline block being longer in Experiment 7 and there being less distraction from the peripheral characters, as suggested in the results section above. That said, the MT group still have the largest proportion of re-fixations and the longest re-inspection durations in block 2 (both in absolute, and

[5] It should be noted however that such comparisons between Experiments 5 and 7 are not strictly valid for three reasons: (i) Because the interest areas used in Experiment 7 were defined more precisely and were therefore more constricted than Experiment 5; (ii) Because the Eyelink II tracker used in this Experiment has a faster sampling rate than the Red-Eye III used previously (500Hz as opposed to 50Hz); (iii) Because there are more trials in Experiment 7. It is for these reasons that statistical comparisons of the eye movement data between experiments are not carried out. Nevertheless the results obtained within Experiment 7 itself should clarify the findings of Experiment 5.

relative terms expressed as the difference from baseline), though these differences are not significant when the display is gaze contingent.

It appears that the ability to re-fixate per se, and not necessarily re-checking in peripheral vision, helps maintain optimal accuracy levels for all groups under normal viewing conditions (Exp. 5). Eliminating the ability to re-fixate the letter likely contributed to the lower accuracy scores of Experiment 6. Note, however, that this does not preclude the finding of *longer* re-inspection durations for the MT group in Experiment 5, just that a quick glance back will suffice for the NT and BT groups, whereas the MT group need a little longer. Whereas all training groups benefit when re-fixations can be made, this need is greater when training is directed towards the Move centre in isolation, as manifest in the MT group's protracted re-inspection durations in Experiment 5. It is possible to re-fixate the letter when the display is gaze contingent, hence optimal accuracy levels are maintained in the present experiment. But the fact that re-inspection durations, or the number of re-fixations, did not (significantly) differ between groups in Experiment 7, means that there is something about the gaze contingent display which diminishes the effect of MT on the initial processing of the central letter. It is less likely that this has anything to do with participants strategically adapting to extract the required information from the centre, as they may have done in Experiment 6 by purposefully withholding target directed eye movements at the start of the trial, because the task is again self-paced, the central letter does not offset and is always available if necessary. Rather, the reduced need to re-visit the letter before responding for the MT group is more likely linked to adequate processing of the central letter during the initial processing. Does MT lead to premature disengagement from the central letter only when the target is concurrently visible amongst the circular array of characters? This is related to the issue of early covert attention shifts when the letter is first being inspected, which is discussed next.

The different possibilities for the results of Experiment 7 which would allow inferences to be drawn about covert attention were outlined when this experiment was introduced. The results obtained show that initial central gaze durations do not differ between groups, as in Experiment 5. I argued that this outcome would shed light upon premature disengagement from the central letter depending on whether the MT group still exhibited longer re-inspection durations: if they did, this would suggest that the top down MT strategy alone is sufficient to hinder the processing of the central letter (i.e. bottom up activation from the target contained within the peripheral array is not also needed). Given that covert attentional shifts are less likely in the absence of a visible saccade target, the conclusion from this result would be that MT causes processing of the letter to be less efficient and eye movements to be directed to soon. This explanation would not require reference to differences in the timing of covert attentional shifts. However, the MT group *did not* show extended re-inspection durations in Experiment 7, so the alternative account is required: that MT is necessary to cause premature disengagement from the central letter, but not sufficient. Only in Experiment 5 when the number target is concurrently visible do we have evidence the central letter has not been processed adequately at the start of the trial. This processing deficit may well be caused by early shifts of covert attention when the letter is being initially inspected, brought about by the combination of using the top down MT sequence *and* the target number being visible in the peripheral array. In Experiment 7 the MT group would be much less prone to make premature shifts of covert attention since the target number is not visible simultaneously when they are first processing the central letter. Hence, although the largest increase in re-inspection durations was observed with the MT group, this difference is not statistically significant when the display is gaze-contingent.

It is conceded of course that the premature-covert-shift explanation (when the entire display is viewed normally and processing of the central letter is self-paced) relies on a null effect from Experiment 7, which demands further studies if the conclusions are to be confirmed with confidence. Two manipulations for future investigations become apparent.

First, to assess the value of re-fixations in maintaining accuracy, according to the hypothesis that early covert shifts occur only for the MT group and only when the circular array of potential target is simultaneously visible, it would be necessary to make the central letter alone gaze-contingent. Under these conditions, with the additional proviso that the letter is only visible during self-paced initial central gaze durations, thereafter being unavailable for re-fixation, we could establish whether accuracy declines because of early shifts of covert attention. According to the arguments presented it should, because the letter would remain on the screen for as long as participants need to look at it at the start of the trial (unlike Exp. 6 which may have induced some deliberate, thus aberrant, tactic for extracting the required information from the centre more efficiently). Thus the only difference between Experiment 5 would be that re-fixations could not be made; and if early covert shifts under these conditions mean that re-fixations are necessary for correct responding, accuracy should decline for MT participants.

The second suggestion for testing the validity of the covert shift explanation is to systematically vary the Stimulus Onset Asynchrony (SOA) of the peripheral array characters. This would test the temporal parameters of early movements of attention unaccompanied by overt saccades: when the timing is optimal, a detection advantage should ensue for targets which appear concomitant with a covert shift of attention (i.e. even when fixation remains at the centre). Other manipulations with the peripheral array would also help confirm and clarify the conclusions drawn in this chapter. For example, place holders could be used in a similar gaze contingent procedure, tagging the location of peripheral characters, which only become fully visible when foveated. This would shed light on whether a visible saccade target per se (i.e. irrespective of target identity) affects the deployment of covert attention when training is directed towards the Move centre alone.

These proposals for additional research aside, if one accepts the early covert shift explanation offered to account for the results of Experiment 5 (and conversely the lack of a MT detriment in Experiment 7), then the suggestion that the MT group do not really need to look for longer, but did so in Experiment 5 simply because the letter was always available, seems unlikely. The letter was always available to be re-inspected in Experiment 7 if this is necessary to maintain performance levels; but it appears that this is not required with the gaze contingent paradigm. Therefore one can conclude with greater surety that the early covert shift hypothesis is correct, and that the longer re-inspection durations of the MT group in Experiment 5 reflect this, and not the more plain account that MT participants look back for longer just because they can. (Though it is noted again here that additional work would be necessary to corroborate this claim, as outlined above).

One of the aims of the work undertaken in this thesis was to appraise the interplay between top down training and bottom up stimulus signals upon eye movement control. The findings of the three experiments conducted in this chapter have allowed this objective to be met. We have evidence that, at least under the present testing conditions, both bottom up input *and* top down control are required to give rise to a detriment associated with directing training at the Move centre in isolation. Moreover, there is also evidence of top down control over eye movements which adds to our understanding of levels 4 and 5 in Findlay & Walkers (1999) model, consistent with goals. It is likely that participants concentrated efforts to extract information from the central letter to maintain accuracy levels in Experiment 6 (where the central letter disappeared, thereafter no longer being available for re-inspection), thereby counteracting the 'pull' of the Move centre seen in Experiment 5. One would expect this to involve level 5 of the WHEN pathway, though *temporal preparation* (level 4) may also be involved since the letter offset after a predictable temporal interval. Similar evidence of voluntary control over eye movements is provided by Tse and colleagues (2002), who show that attentional capture by abrupt onsets is not compulsory: when the task is to remain fixated exogenous saccades can be prevented.

Likewise, there is evidence of *cognitive processing* (level 4) biasing activity in the Fixate centre, BT leading to longer fixation durations when first inspecting the central letter in Experiment 7. This is the only case of conjoined training directed at the Move and Fixate centres in concert being a hindrance; usually throughout the thesis BT produces the best performance. This illustrates that BT may not be useful if the demands placed on the Move centre do not impede upon task performance (possibly due to consolidation via learning, or the lack of bottom up influences).

Lastly, there are also findings which pertain to the utility of external re-enforcement when training eye movements. Conclusions are speculative because the results are not clear cut, but generally, veridical feedback does not seem to be useful. It may have an interfering effect when the Move centre dominates (as discussed in Exp. 5), but at best, it serves no purpose in the experiments I have presented, performance never being better in the FB compared to the NFB conditions. Participants seem to respond more cautiously when veridical feedback is withdrawn, and this may be significant for certain applied areas where eye movements and perceptual decisions have important consequences.

This leads onto the penultimate chapter, and final experimental chapter, of this thesis. Is training directed at the Move centre a problem for hazard perception in driving scenarios? In light of the results presented thus far from more controlled lab settings we are better equipped to tackle this question. Chapter V, therefore, uses video clips of driving situations with different training groups.

5. Chapter V – Training Eye Movements and Hazard Perception in driving scenarios

One of aims of this PhD thesis was to relate eye movement training to hazard perception in driving, grounding the results obtained in an applied area, thus giving practical relevance. In particular I proposed to relate the hypothesized Move–Fixate competition of Findlay & Walker's (1999) model to the UK government initiative 'Think Bike'. This campaign encourages drivers to look frequently and repetitively from the left to the right at junctions, the aim being to reduce so called 'Look But Fail To See' accidents (LBFTS, Brown, 2002) involving motorbikes. The visual scanning behaviour endorsed by Think Bike has been mentioned already in this thesis, because it is possible that in encouraging eye *movements,* activity in the Fixate centre may be reduced, and as a result important objects may be missed even when they are fixated. Experiment 8 thus tackles the issue of whether the left-right scanpath publicised by the Think Bike campaign is a problem for hazard perception in driving.

The literature associated with this question will be discussed. First, however, it is worth summarising the conclusions from Chapter IV so that we begin with a sound understanding of the potential detriment linked to directing training at the Move centre alone. It is clear from the experiments that have been described that any hindrance brought about by training people were to look is subtle. If indeed it can worsen performance, this only presented in Experiment 5 when the array containing the target was concurrently visible and the task was self-paced. It was therefore argued that *both* the top down Move Training strategy *and* the bottom up input from the visible circular array are necessary to cause a premature shift of covert attention (the likelihood of an [overt] eye movement being made in advance was thought to be slim because Initial Central Gaze Durations never differed between groups, and were comparable between experiments). What is more, it seemed that competition from the Move centre inducing an early shift of covert attention when the circular was always visible could be suppressed. Participants may have strategically adapted to maintain central fixation and extract the required information from the letter in Experiment 6, where the letter disappeared after a short time. With these previous findings and conclusions borne in mind I proceed to address the background to the experiment covered in this chapter.

Given the delicate nature of any performance detriment linked to Move Training, can it cause detection failures in driving scenarios? There is certainly evidence which may be likened to the converse of the Move centre taking priority in the applied domain of driving. Crundall and colleagues (Crundall, Shenton, & Underwood, 2004; Crundall, Underwood, & Chapman, 1999) have demonstrated that when attention is reflexively captured by a hazard (bottom-up), or volitionally directed towards following the car ahead (top-down), the ability to notice events in the periphery is impaired. One may argue that this demonstrates the Fixate centre dominating the competitive relationship. However, although the LBFTS accident causation factor is supported by considerable research (Brown, 2002; Herslund & Jorgensen, 2003; Martens & Fox, 2007), there is no evidence, to the author's knowledge, which connects this inattention to top down eye movement training strategies biasing activation in the *Move* centre.

Despite this gap in the literature there is good reason to believe that advice offered to drivers which promotes broadening visual search range with regular and vigilant scanning (e.g. Coyne, 1997; Mills, 2005) will not be advantageous. For one thing this advice is often based on the premise that the eye movements of novice drivers should be made to resemble those of expert drivers –indeed constantly moving the eyes from one side of the road to the other, as promoted by the Think

Bike campaign, is indicative of the wider spread of search seen in experienced drivers (Crundall & Underwood, 1998). However, it is also know that novices fixation durations tend to be longer than experienced drivers' (Chapman & Underwood, 1998); therefore increased activation in the Move centre associated with a top down strategy which encourages eye movements may create an artificial deadline for each fixation, not allowing novices the time they require to extract the same information as their more experienced counterparts. We have already seen evidence that procedures which give rise to comparable scanpaths between experts and novices do not necessarily lead to equivalent performance gains (Donovan et al., 2005).

Novice drivers are overrepresented in accident liability statistics (Clarke, Ward, Bartle, & Truman, 2006; Elander, West, & French, 1993), and it is also acknowledged that a worrying proportion of collisions on the road involve cars and motorbikes (Clarke, Ward, Truman, & Bartle, 2004). Hence, advice about the deployment of visual resources when driving, particularly with reference to motorbikes, has emerged. This advice however is often piecemeal, coming from specialists in applied domains, without due reference to established models of eye movement control. In this case, Findlay and Walker's (1999) model seems particularly important.

LBFTS accidents involving motorbikes may be of special interest because even experienced drivers are at risk of these detection failures. While there may be attitudinal reasons for this (Crundall, Bibby, Clarke, Ward, & Bartle, 2008), there are two purely perceptual reasons which are more relevant to this thesis.

First, motorbikes are small, and it is known that there is a timescale from coarse-to-fine for the emergence of such high spatial frequency information (Hughes et al., 1996). Large objects are noticed earlier and take precedence. This explanation has found empirical support. Crundall, Humphrey & Clarke (2008) used briefly

(250ms) presented snapshots of either cars or motorbikes approaching t-junctions (mixed with no vehicle trials), and their participants had to judge whether a vehicle was present or not. The distance of the approaching vehicles was manipulated: cars and motorbikes were located at near, intermediate, or far distances along the road. It was found that with far distances motorbikes were spotted less than cars, and moreover that when far motorbikes *were* detected response times were longer. In accordance with the spatial frequency explanation the authors argue that far motorbikes form a smaller image on the retina (than far cars) which is only disambiguated from the surround after a delay. It is also noted that Crundall et al.'s sample had an average of 8yrs driving experience; hence, noticing motorbikes at junctions may be a problem for all road users, independent of experience, due to the limits of the visual system.

The problem of motorcycles' conspicuity, because of their high spatial frequency, may be further compounded by car drivers' expectations. Motorbikes are less numerous in traffic (at least in most western countries like England), and this may cause an unhelpful bias in attentional set. Because car drivers do not encounter motorcyclists as frequently, they may not look for them as readily as other vehicles or types of hazard. Hence, perhaps *because* motorbikes only make up around 1% of traffic, they still account for around *14%* of deaths or serious injuries on the road (DfT, 2008b). Indeed, attentional set has been studied in the laboratory in relation to the issue of motorbikes. Using a simulated driving task Most & Astur (2007) had participants search for either yellow or blue arrows when they reached the intersections of the virtual cityscape they were driving through. The arrow indicated the direction they should turn. At critical intersections a yellow or blue motorcycle veered into their path. The important finding was that the rate of collisions with the motorcycle was found to be higher when its colour did not match the arrow colour they were searching for. Attentional set may therefore weight priority, and in real driving situations, car-motorbike crashes may therefore be explained by car drivers not keeping motorcylces at the forefront of their minds simply because they are encountered less often.

The use of arrows in the study by Most & Astur (2007) may be related to the Move Training strategies described in this thesis. Perhaps activity in the Move centre generated when moving the eyes according to a training principle only leads to LBFTS-like errors when there is a lack of correspondence in attentional set.

Given the evidence there is good reason to believe that, despite their superior driving skill, eye movement training protocols may still present a problem for noticing motorbikes in experienced and novice drivers alike. Because of the reciprocal inhibition between the descending pathways in Findlay & Walker's (1999) model, training people *where* to look may only serve to exacerbate the underlying reasons why LBFTS errors occur. The experiment presented in this chapter therefore tests whether the left-right scanpath suggested by the Think Bike campaign is a problem for hazard perception in general. A range of video clips of driving scenarios were used, and the hazards differ, to represent the wide range of potential dangers that drivers encounter on the road.

5.1. Experiment 8 - Can training people where to look lead to detection failures in a driving task?

The present experiment assesses whether advice which emphasizes eye *movements* in drivers, such as repeatedly looking from left to right at junctions (Think Bike! campaign, DfT, 2008a) or broadening visual search range with more frequent scanning (Coyne, 1997; Mills, 2005), is likely to bring about improvements in hazard perception for drivers. One of the central themes of this thesis is that such advice might actually make people worse because it may decrease Fixate centre activity by promoting competing activity in the Move centre –this in turn may cause detection failures akin to the LBFTS accident causation factor (Brown, 2002). We have a good basis for evaluating this potential outcome given what we have learned from the preceding experiments covered herein.

A hazard perception task containing video clips of driving scenarios was employed in Experiment 8. The video clips themselves were originally developed by Jackson, Chapman & Crundall (2008), and include a range of typical situations encountered when driving, filmed on the road from the drivers perspective. Every clip contained one pre-defined hazard, and participants were required to press the space bar as soon as they detected it. Hazards were defined, as in Jackson et. al, as an event that would require the driver to brake or take evasive action in order to avoid an accident. The onset of the hazard was also defined according to this criterion as the earliest point in time at which its occurrence could be anticipated. When participants pressed the space bar the screen went black (pausing the video clip) and they were asked three questions to gauge their hazard detection accuracy: (i) What caused the hazard? (ii) Where was the hazard located? (iii) Why was it dangerous? Such questions help ensure that the three levels involved in Situational Awareness (perception, comprehension, and projection respectively) are taken into account (cf. Endsley, 1995; Jackson et al., 2008).

Participants were assigned to one of four groups with different procedures to be employed while carrying out this task. The groups were slightly different to the training conditions used previously, one, to accommodate a more real-world task, and two, to add additional control measures to the design.

The main question of this investigation was addressed with the first group. Participants allocated to this group were required to continuously and regimentally scan from left to right, in an exaggerated simulation of the advice suggested by the UK Department for Transport 'Think Bike!' campaign (DfT, 2008a), as well as similar advice recommended by other driving experts (e.g. Coyne, 1997; Mills, 2005). Specifically, participants in the first group were required to fixate the centre of the screen, followed by the left-, then followed by the right-, hand side; this sequence was to be repeated for the duration of a video clip. Two possibilities were predicted about the influence of this eye movement strategy based on the arguments outlined above: (i) it would reduce hazard perception accuracy; (ii) it would extend reaction times (as measured from the onset of the hazard to the keyboard response).

The second group was based on combined Move and Fixate training, as outlined in the preceding chapters. It was suggested at the end of Experiment 5 that the best way to implement eye movement training for drivers is to concentrate efforts *both* towards locating, *and* towards processing important objects in the visual scene. I offered the specific idea that integrating the benefits of Move and Fixate training in concert for drivers could be as simple as advising them to 'look for longer'. Hence "...drivers could be advised to... 'Look right CHECK, look left CHECK, then right again'" (section 4.1.3, p.153). On this basis the procedure employed by the second group was an adaptation of the left-right scanpath used by participants in group one. Participants were likewise required to continuously scan (left-centre-right-centre; repeat) except with the additional stipulation that they should remain fixated for three seconds before they left the area they were currently inspecting. It is not certain whether this will lead to an improvement over the performance of the first group because the strategy is quite contrived; nevertheless, the manipulation is such because it will provide important control comparison data.

Two additional control groups were also included: participants assigned to the third group were required to verbalize the left right sequence (i.e. actually say "left, centre, right, centre..." etc.) without the requirement to make eye movements according to this sequence, as with group one. The aim was to control for the spatial component of the eye movement training advice (i.e. to establish whether the repetition *locations* per se is accountable for any observed effects with group one, or whether the results are specific to the requirement to move the eyes). The fourth and final group provided a control comparison where participants were not required to conform to any training advice throughout.

Eye movements were not recorded in Experiment 8. The principle reason for this omission is pragmatic: as alluded to when introducing eye tracking research in Chapter III, recording eye movements for dynamic video images is incredibly complex and time consuming. There are thousands of frames per video clip in the current experiment, and the regions of interest would vary wildly both within and across clips. It is possible to incorporate meaningful eye movement recordings into such a design (see Reimer & Sodhi, 2006; and Shinoda, Hayhoe, & Shrivastava, 2001), but the primary objective was to ascertain whether the effect of encouraging eye *movements* by training people where to look is robust enough to yield a performance detriment for the driving task which can be identified in the manual response data.

5.1.1. Method

Participants

Sixty four naïve paid participants (mean age 21 yrs, range 18-39; 35 female) were recruited from the University of Nottingham's student population and the surrounding local area. All reported normal or corrected-to-normal vision, and were paid an inconvenience allowance for their time.

Materials & Apparatus

A short questionnaire was used which collected demographic information, some specific to driving (including but not limited to: date driving test was passed, self-estimated annual mileage), as well as three self-report measures of driving ability (1-6 Likert ratings for overall driving ability, awareness of other road users, and confidence when driving in general). Twenty five video clips taken from Jackson et al. (2008), with permission, were used throughout the study. These clips were recorded from the windscreen of different cars on a Sony HVR-A1E camera, and the footage included various road types and hazardous scenarios. The majority of the clips (14) contained spontaneously occurring hazards, 11 clips were staged. Hazards included events such as cars reversing, changing lanes, emerging from junctions, pedestrians stepping into the road, cyclists swerving to avoid parked cars etc. Each clip contained one specified hazard, as defined in Jackson et al as the only event within the clip that would require the participant to brake or take other evasive action in order to avoid an accident if driving. Hazard onset times (judged as the earliest point in time at which the hazard could be detected) ranged from 1.2 to 25.1 seconds, and the clip ended once the full hazard had been shown. A 24" iMac 6.1, running at 1920x1200 pixel resolution, was used to display the video clips to each observer via MatLab software.

Design

Participants were allocated to one of the four experimental groups at random, thus giving four between-groups factors of the Training variable: eye Movement Training (MT); Both Move and Fixate Training (BT); verbalized Spatial Control (SC); and No Training (NT). Participants were equally divided between these groups (*N* = 16). The specific procedures adopted by each experimental group are outlined in full below.

Data was collected for two major dependent variables: hazard detection Accuracy, and Reaction Time (RT) from hazard onset. Participants pressed the space bar when they believed they had detected the hazardous event in a clip (this paused the video and the display was replaced with a black screen). During the pause the experimenter scored answers given to three questions (1. What caused the hazard? 2. Where was the hazard located? 3. Why was it dangerous?). In order to standardise the measure of hazard detection accuracy, each answer was given a score out of two, with a score of one being reserved for answers judged as partially correct (the scoring system was based upon that of Jackson et al. [2008]). To promote objectivity participants had to verbalize keywords in response to each question in order to obtain a maximum score of 6 when they pressed the space bar. For example, in one clip the hazard was a cyclist swerving out abruptly from the left to avoid a stationary vehicle, in which case participants' answers to each of the above questions respectively must include the words (or synonyms thereof), "bike", "left", and "obstruction" in order for a score of 6 to be awarded. Answers following all space bar presses were assessed in this way (i.e. with reference to the single specified hazard in the clip). Space-bar presses with a total score lower than 5 were considered incorrect.

A minor dependent variable was also considered: Number of Space-bar Presses per clip. This measure was included to establish whether any difference in accuracy and reaction time between groups could be explained by systematic variations in frequencies of responding. For instance, if one group pressed the space bar more often they could by default improve their probability of answering correctly. Also, assessing the number of responses made sheds some light on how cautious participants are. Although explicitly instructed to regard hazards as only those events which would lead to an accident in the absence of an appropriate driver response, over-cautious drivers may have less stringent criteria, which would be reflected in a larger number of space bar presses.

The statistical analysis carried out with these data also considers whether there is a relationship between the transition from novice to advanced driver and the development of hazard perception skills (cf. Underwood, 2007) by splitting participants into two groups, based on either high or low experience in months, or high or low mileage. These measures of driving experience are also used to check for correlations with the dependent measures.

Procedure

On arrival participants filled out a consent form, and the demographic questionnaire mentioned above. Participants were provided with instruction sheets in which the primary hazard perception task was explained, as well as the secondary task, which differed depending on the experimental group to which they had been allocated.

Instructions for the MT group asked them to move their eyes from the left of the screen, to the centre of the screen, and then to the right of the screen, and repeat this eye movements sequence throughout every video clip. Participants were required to pause, maintaining fixation on each region specified by this sequence for 1 second. The precise location to fixate was not specified, but participants were told to make eye movements according to the left-centre-right-centre sequence based on their rough approximation of the screen being divided into thirds. The instructions for the BT group were identical, with the exception that participants were told to look for longer (3 seconds) in between the lateral eye movements required by the sequence. The SC group's instructions reflected the eye movements sequence described, but instead of moving their eyes in the left-centre-right-centre sequence, participants had to simply verbalize this sequence (i.e. actually say "left, centre, right, centre…" etc.) while completing the hazard perception task. There was no secondary task for the NT group; hence instructions were only given for the primary hazard perception task, and these instructions were identical to the primary task instructions for the other three groups, informing participants to press the space bar when they detected a hazardous event that would necessitate evasive action if driving.

The experimenter confirmed that participants understood what they had to do and clarified any misunderstandings if necessary before proceeding with the experiment. The presentation order of the clips was randomly determined, and as the clips proceeded, participants were asked to respond as quickly and accurately as possible to emerging hazards by pressing the space bar. When they did so the clip was immediately paused, being replaced with a black screen. During these brief interludes the experimenter asked each of the three questions pertaining to hazard perception accuracy (i.e. What caused the hazard? Where was the hazard located? Why was it dangerous?) in the given order, and the experimenter rated participants' verbal answers as described.

Each clip was shown in full to all participants, and did not terminate if the hazard was correctly identified. A single testing session for one participant lasted approximately 25 minutes. During each clip the experimenter observed the participant closely to ensure that the secondary task procedure for the testing session in hand was being adhered to. To help ensure the eye movement sequences were being adhered to eye movements were monitored using a suitably angled mirror. The experimenter reinforced the requirement to carry out the primary hazard perception task *as well as* the secondary strategy (or control thereof) if there was any deviation from the procedure.

5.1.2. Results

Results are presented for each dependent variable: reaction times (from hazard onset to correct space bar press), hazard detection accuracy, and number of space bar presses per clip. Training groups were compared for these measures, and the results of these analyses are presented first. Experiential differences were also evaluated, using median splits for high/low months of driving experience and high/low self-estimated annual mileage. These analyses follow-on from the first, together with assessment of any correlational relationships between driving experience and the variables recorded. One subject (from the BT group) was removed from all analyses for having an accuracy score >5 standard deviations below the overall mean.

<u>*Reaction Times*</u>

For clips in which the hazard was correctly identified (excluding incorrect space bar presses) the average time that elapsed between a hazard onset and a correct response was 1.55s (Std Dev = 0.45). However, the analysis between group means only revealed a trend in the data ($F (59, 3) = 2.7$, $MSE = 0.5$, $p = 0.063$). Planned comparisons with Tukey's HSD showed a significant difference between the SC and NT conditions only ($p = 0.048$), accounting for the trend with the omnibus statistics. Reaction times for the SC group were longer than reaction times for the NT group (see Fig. 5.1, below). Although the MT group have a longer delay than the NT group before correctly responding to a hazard (by ~310ms), as predicted, this difference was not statistically significant ($p =0.205$).

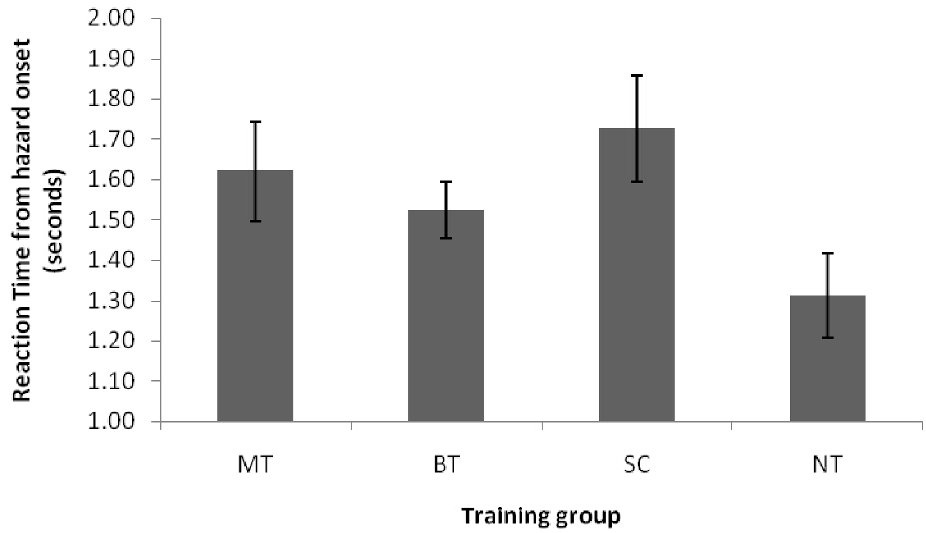

Fig. 5.1. Mean reaction times from hazard onset to correct response for each training group (MT = Move Training –left-centre-right-centre scanpath; BT = Both Training –same scanapth, except fixation is maintained at each location for 3s as opposed to 1s; SC = Spatial Control –verbal repetition of "left-centre-right-centre" sequence; NT = No Training –control group without a secondary task). Error bars show standard error of the mean.

Hazard Detection Accuracy & Number of Spacebar Presses per clip

To validate the criterion used for accuracy a frequency histogram is plotted (Fig. 5.2); this demonstrates that the scoring system employed was valid, as the majority of responses were above the cut-off point for a correct answer (=> 5), while incorrect responses were most commonly given a score of 0.

Across all participants the average percentage of clips in which the hazard was correctly identified (irrespective of the number of times the space bar was pressed) was 75.9% (Std Dev = 13.5). However, when the analysis was repeated with the accuracy data the ANOVA revealed no significant differences between groups. Likewise, groups did not differ in the number of times they pressed the space bar per clip (overall $\bar{x}$ = 0.9, Std Dev = 0.2; this analysis included clips in which the hazard was not correctly identified). Group means for hazard detection accuracy and number of spacebar presses per clip are tabulated below (Table 5.1).

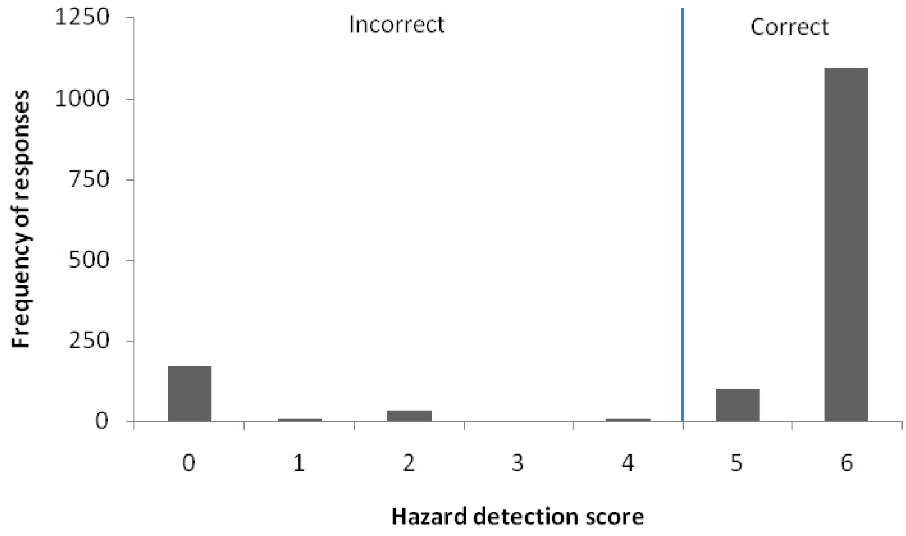

Fig. 5.2. Frequency histogram of accuracy scores given each time the space bar was pressed

	Training Group			
	MT	BT	SC	NT
Hazard Detection Accuracy (%)	75	78	72	79
	3.0	*2.2*	*4.3*	*3.6*
Average Number of Space Bar Presses (per clip)	0.90	0.94	0.84	0.93
	0.05	*0.04*	*0.05*	*0.06*

Table 5.1. Mean hazard detection accuracy and number of space bar presses per clip for each group. Standard errors are italicized.

Driving Experience

Driving experience was also examined. Based on two median splits, one for ‘months since passed test’ (Mdn = 32.5; inexperienced $\bar{x}$ = 18.6, experienced $\bar{x}$ = 57.5), and one for ‘estimated annual mileage’ (*Mdn* = 1000; inexperienced $\bar{x}$ = 387, experienced $\bar{x}$ = 5218), experiential differences were present ($t_{34.2} = -6.8$, $p < 0.001$; $t_{30.6} = -7.6$, $p < 0.001$, respectively. [Note that degrees of freedom are adjusted as Levene’s test for equality of variances was significant in both cases]). Groups were compared on this basis; however the independent samples t-tests revealed no significant differences for any of the dependent measures. Had these analyses been significant it was the intention to see which clips best distinguished between novice and experienced drivers, and then repeat the original analysis only using these clips; this may have magnified any differences in the original analyses. Due to the lack of experiential effects however this was not carried out.

Finally, the two measures of driving experience were correlated with each of the dependent variables. No significant correlations were observed. The lack of experiential effects in this study (as opposed to Jackson et al., 2008, who did find differences relating to driving experience with the same clips) likely reflects the fact that this study was not purposefully set up to distinguish between novice and experienced drivers. The novice group in the present study had on average 12 months more driving experience than the novice group who took part in the experiment of Jackson et al. Other differences in the design between these two experiments are also likely to explain why no effects of driving experience were found here (for example, in Jackson et al. the main focus of the investigation was to assess hazard *anticipation* by asking participants what happened next while the video clips were paused).

5.1.3. Discussion and Chapter Conclusions

On the basis of Findlay & Walker's (1999) model of saccade generation and the results of Experiment 5 from the previous chapter –which identified that training people where to look may be a hindrance for the processing of fixated objects –it was predicted that advice which encourages eye movements in drivers may be detrimental to hazard perception. This potential outcome was grounded in the idea that increased activity in the Move centre (controlling the locations selected for visual inspection) inhibits activity in the Fixate centre (controlling the duration that each fixation lasts), and as a result the processing of information when fixating may be impaired if eye movements are overly encouraged. This is particularly relevant because of the recent Department for Transport Think Bike! campaign, which endorses a repetitive left-right scanpath at junctions (DfT, UK, 2008a). Based on Findlay & Walker's framework, promoting such a strategy may actually increase the incidence of LBFTS accidents involving motorbikes (Brown, 2002), an outcome completely polarised from the campaign's main objective. However in the current study, although eye movement training similar to the Think Bike! campaign did lead to longer reaction times to driving hazards, this difference was not statistically significant. This is reassuring because it suggests that the potentially negative effects of competition between the Move and Fixate centres do not necessarily apply to a widely publicised road safety campaign.

Why was eye movement training not detrimental to hazard perception in this instance? One possibility is that the strategy employed by the MT group in this investigation did not focus enough on moving the eyes quickly and continuously; had it done so the chances of more hazards being missed or responded to with increased latencies could have been be much higher.

Of course, an alternative reason that MT was not detrimental here may well be because the effect is delicate. It was evident in Chapter IV that subtle changes in experimental design attenuate any detriment associated with MT. One of the arguments presented to account for this was that participants can strategically override the 'pull' of the Move centre away from fixated objects if necessary. Such a mechanism of voluntary control was proposed to account for the results of Experiment 6. This may also come into play with the current experiment, participants tempering the negative effects of MT by concentrating efforts to extract information more efficiently when fixating.

The above argument may be related to research undertaken by Chapman, Underwood, & Roberts (2002). Recording eye movements on real roads in traffic, Chapman et al. showed that novice drivers abandon simple eye movement training schedules on highly demanding dual carriageways. They suggest that this is because the implementation of the trained strategies interferes with the effortful task of maintaining a safe lane position (which is not yet automated in the novice driver). This demonstrates voluntary control over eye movements. Maybe the implementation of eye movement training can be modulated up to a point, so that the strategy can still be executed but tempered according to the demands of the roadway if it enhances unhelpful competition between the Move and Fixate centres. This would accommodate the supposition that the MT group in this experiment do indeed adhere to the scanpath stipulated by the training strategy[6], yet in such a way that it does not detrimentally effect performance. However, at the point at which task demands become too great for this modulation to be carried out, the training strategy may be abandoned (cf. Chapman et al.). Participants spontaneously discontinuing with inefficient visual training strategies has also been reported by Shapiro & Raymond (1989, p.240), strengthening this suggestion.

However, as the more naturalistic task used in Experiment 8 is entirely different from the basic paradigm employed in the previous chapter, it could be that a detriment linked to training directed at the Move centre is confined to more controlled (but more artificial) laboratory situations. The lack of eye movement recordings in Experiment 8 make it difficult to establish this for certain, but the

[6] It should be noted that eye movements were closely monitored using a suitably angled mirror, a procedure previously documented by Crundall, Dewhurst & Underwood (2008), and were in accordance with the experimental procedures.

absence of these measures was in part a price paid for the higher degree of ecological validity (though the author acknowledges that, given the time, incorporating eye tracking into the present design would have been advantageous).

Nevertheless, if overemphasising the importance of visual scanning, and underemphasising the importance of information processing when fixating is a genuine concern for driving, we would hope that the effect is robust enough to present in behavioural data as taken here. The fact that it does not is reassuring, because it suggests that advice offered by experts in applied fields, who perhaps develop visual training techniques without due reference to established models of eye movement control (Coyne, 1997; Donovan et al., 2005; Mills, 2005), does not necessarily exacerbate the LBFTS problem. However, the results of Experiment 8 by themselves do not negate the premise that training people where to look, alone, can lead to detection failures. LBFTS-like errors may have occurred, but these remained hidden because occulomotor statistics were not recorded. Moreover, despite the large sample size used here (*N* =64), perhaps the experiment is underpowered statistically (each group contained 16 subjects, and only 25 data points contributed to each subjects mean) to reveal an MT detriment for the driving task. Finally, despite the effort made to simulate the real world activity of driving, perhaps the experiment in hand failed to capture inattention as it occurs on the road when actually driving a car. One important difference between the way MT was operationalised here and the way left-right scanning is used when driving, is that drivers make head movements. This is particularly the case at junctions, which are the focus of the Think Bike! campaign. How reciprocal inhibition between the Move and Fixate centres translates into head-movements is a very interesting question. At this stage however it is unfortunate that this issue is outside the scope of this thesis.

With the differences between the task used here and driving on the road borne in mind, it is notable that the SC group of Experiment 8 did have significantly longer reaction times from hazard onset (in the pre-planned comparison). This might reflect that the requirement to verbally repeat a sequence of spatial locations ('left-centre-right-centre…' and so on) implicitly affects eye movements, possibly increasing competition between the Move and Fixate centres in the manner described. The effect of this may be further compounded by conflict between what the SC group were saying and where they were looking, because there was no stipulation that their eye movements should mirror the sequence they had to verbalise. Therefore one may contend that the competitive interaction between the Move and Fixate centres can be overridden or tempered, but not when it is influenced by the requirement to repeat a series of words which reference spatial locations. Without eye tracking data it is not possible to draw firm conclusions about the relationship between what the SC group verbalised and where they actually looked, however it is of interest to note that conflicts between the verbal and visual modalities may cause interference which is detrimental to drivers' hazard perception skills. This is particularly topical because it has implications for the use of mobile telephones by drivers. It has previously been shown that when the conversational partner is not present to appreciate roadway demands, their conversations with the driver are not regulated accordingly (Crundall, Bains, Chapman, & Underwood, 2005). The authors point out that this is a problem even for the use of hands-free phones when driving, because conversations continue regardless of road type, emerging hazards, or fluctuations in traffic, and may therefore be a distraction. The present findings suggest that the drawbacks of engaging in conversation with anyone other than an alert and responsible passenger may be particularly apparent if the topic of conversation accesses visuo-spatial information[7].

Experiment 8 is encouraging because it provides evidence that a widely publicised governmental campaign does not necessarily impair hazard perception in drivers, even though Findlay & Walker's (1999) model and the results of Experiment 5 predict it could. The Think Bike campaign may be a good thing, not necessarily because of the visual scanning it endorses per se, but because it may alter attentional set (cf. Most & Astur, 2007; Thompson, Underwood, & Crundall, 2007) so that motorbikes are held in mind; thus reducing LBFTS accidents where cars violate motorcyclists' right of way. Nevertheless, an additional caveat is necessary. Although simulation of the eye movements encouraged by the Think Bike! campaign was attempted, the experimental paradigm used was only an approximation of 'real-life' driving behaviour. If drivers do not implement available advice on eye movements appropriately when they are confronted with real hazards on the road, there may still be cause for concern. Questions revolving around whether drivers correctly interpret the advice on visual search available to them remain avenues for further research.

[7] I should also point out that pilot data from the same laboratory, not reported here because of the difference in emphasis of the research (in car mobile phone use), has revealed no effect of other verbal secondary tasks on hazard detection performance with the same video clips as used here. This adds weight to the argument that it is spatial referencing with the SC group that drives the effect reported in Experiment 7, not verbal interference per se.

6. Chapter VI – General Discussion

6.1. Discussion Outline

This Chapter will begin with a summary of the main findings covered in the thesis. I will address the results of each experiment in turn and draw together the conclusions of each chapter. From here a section will then be devoted to the implications of this work for Findlay & Walker's (1999) model, including some suggestions for further research. Finally, the last section of dialogue draws the discussion to a close, offering a few additional parting comments on practical implications.

6.2. Review of experimental chapter conclusions

Summary of Chapter II

The experiments of Chapter II set out to understand the behavioural parameters (manual response times and accuracy) of eye movement training as they relate to the Move and Fixate centres of Findlay & Walker's (1999) model. In particular, the objective was to tackle the question of whether implementing strategic advice for visual search and stimulus discrimination could recruit resources sub-served by the Move and Fixate centres respectively. Could training be directed to these centres modulating saccade generation independently and in concert, and what were the cumulative effects of such training?

Experiment 1 used feature conjunction stimuli of different arrangements (configured uniformly of either red or green, squares or circles; the number of shapes comprising a single array varying between two, three, four, and five) to evaluate training directed at the Fixate centre in isolation. Stimuli were divided into two types which defined the task participants completed. With one set of stimuli (FCN), targets were defined on the basis of their Feature Conjunction (FC) (targets being arrays comprised of either red squares or green circles), and target responses were separated according the number of shapes a stimulus contained (N) (arrays containing even and odd numbers of shapes having different button presses designated). With the second set of stimuli (NFC), the target/response criteria were reversed (targets being arrays containing either three or five shapes), and target responses were separated according to the shapes' feature conjunction (this time red circles and green squares having a different button press designated than green circles and red squares).

The purposes of these complex manipulations primarily concerned ensuring the task was hard enough without specific eye movement training. Thus, contingencies applied to the composition of the stimuli such that the target discrimination judgements could be completed more easily. Trained participants were informed that whenever FCN stimuli were made up of an even number of shapes (i.e. two or four) one of those shapes would always occupy the centre of the display; this was never the case for this stimulus type when an odd number of shapes were presented. Likewise, trained participants were informed that whenever NFC stimuli were made up of red circles or green squares, the centre of the display would always contain one of these shapes; the centre never being occupied when the array consisted of green circles or red squares. Awareness of these contingencies constituted Fixate Training (FT); it was not necessary to remember response pairs for each stimulus category, trained participants could simply refer to the centre of the array: the absence of a shape at the centre would always be tied to one of the button presses, the presence of a shape at the centre would always be tied to the other.

The Reaction Time (RT) results indicated that FT assisted performance; RTs to targets decreasing when implementing the training strategy, over and above the reduction afforded by practice alone (i.e. seen with the untrained [NT] group). This was so for both FCN and NFC stimulus types. The accuracy results also identified a training benefit, however here the advantage of FT was task specific; the training group were better at the FCN task. This result did not fall in line with initial predictions, as it was expected that responding according to the number of shapes present (the N component of the FCN task) would be easier to complete without FT, owing to subitisation processes which allow grouping by proximity and similarity (cf. CODE - Logan, 1996). Conversely, it was predicted that the response discrimination judgements for feature conjunctions would be harder when untrained, in line with Feature Integration Theory (FIT - Treisman & Gormican, 1988), which proposes that parsing feature conjunctions is effortful, requiring attention, unlike such processes as subitisation which the visual system can deal with pre-attentively. However, the fact that a training benefit was observed for the FCN task only seems to go against this argument.

An argument was presented to explain this effect which took into account the initial target identification task. I suggested that the fundamental premises of FIT and CODE are not necessarily called into question by the results of Experiment 1 if one considers that the target identification stage is differentially difficult between the two stimulus types. Identifying NFC targets (combinations consisting of 3 or 5 shapes) seemed much easier than identifying FCN targets (combinations consisting of red squares or green circles), and this was confirmed by participants self-reports. However, assessing the number of shapes becomes much harder when it immediately follows a difficult feature integration (as with the FCN task) –this may be related to temporal attention (cf. the Attentional Blink - Raymond et al., 1992). The unequal difficulty of the N aspect of the task between the two stimulus types is further compounded by two responses being designated for the number judgement with the FCN task, while participants need only dismiss NFC distractors by pressing one key as assigned for catch-trials. The difference in difficultly between the target identification stage and the response discrimination stage is not as great for the processing of feature conjunction, first because it remains difficult throughout owing to effortful feature integration, and second because there is no such lag in temporal processing constraints for the NFC task, the number aspect of the task not impeding upon the later response discrimination part. Later results in Chapter II bolstered this argument, reinforcing the view that feature conjunctions remain more visually challenging than number discrimination judgements. The results to which I refer will be reviewed shortly; however, the next phase of research covered in Chapter II, having addressed training directed at the Fixate centre, evaluated the parameters of training directed at the Move centre.

To begin with, assessing Move Training (MT) concerned identifying patterns of target presentation which are impenetrable to the observer, and which also decrease RTs when advance knowledge of the predictable order of target presentation is given. To meet these aims the original FCN and NFC stimuli of Experiment 1 were again used in Experiment 2, the difference being that multiple stimuli were presented, forming sub-arrays in a 3x3 visual search grid. The perimeter locations of this grid thus contained FCN and NFC exemplars (the central region contained nothing to necessitate visual search away from the central starting position for each trial). Feature conjunction was however irrelevant to the task in Experiment 2: when untrained participants were required to scan the grid for the one location containing an odd number of shapes (i.e. amongst distracters made-up of an even number of shapes), and then respond –also according to the number dimension

–with one button press for 3 shapes, and another button press for 5 shapes. Number was chosen as the dimension for visual search *and* stimulus discrimination here based on the assumption that it would load the Fixate centre less, in accordance with the goal of Experiment 2 to focus solely on MT.

The pattern of target presentation was varied: in one block of trials targets were presented in each corner of the grid in a clockwise order from one trial to the next (a square sequence); in another this pattern was rotated through 45° (giving a diamond sequence); lastly, the pattern of locations was top -left, top-right, bottom-left, bottom-right, and so on… with the final predictable order of target presentation operationalised (giving an 'egg-timer' sequence). These sequences were pitted against random target presentation (see Fig. 2.9 for schematic of sequences employed). The MT group were informed of these different spatio-temporal contingencies governing target presentation within a block, and awareness of each sequence gave rise to a large reduction in RTs (>750ms) over NT or random target presentation. The MT sequences were not differentially difficult to implement, and were largely impenetrable (only one subject correctly guessed and followed the 'square sequence').

Having established the utility of FT and MT independently, Experiment 3 sought to address the consequences of combined training directed towards the Move and Fixate centres in concert. Given that there was a hint that task difficulty played a role in Experiment 1, Experiment 3 was split into two sub experiments, 'a' and 'b'. In Experiment 3a FCN stimuli were used, and both dimensions defining this stimulus type (targets defined on the basis of their feature conjunction; responses classified according to the number of shapes constituting a target) were relevant to the task. Conversely, NFC stimuli were used in Experiment 3b, and likewise both dimensions characterising this stimulus type were relevant to task completion (targets being defined as stimuli comprised of an odd number of shapes; a different response designated for red circles and green squares than for green circles and red squares). In both of these experiments one target stimulus was presented as a sub-array amongst distractor sub-arrays in the overall 3x3 visual search grid (used in Experiment 2) for each trial. The presentation order for targets followed the 'egg-timer' sequence throughout, this intuitively being the hardest to detect, a supposition confirmed with nobody deducing this pattern when untrained in Experiment 2. In addition to an NFT group and MT group, incorporating all the dimensions defining both stimulus types (FCN and NFC) allowed an FT group to be included in the design, as well a group of participants given combined training directed towards *both* the Move and Fixate centres in concert (a BT group). FT again adhered to the stipulations in Experiment 1: the two alternative button presses for the response discrimination aspects of the tasks conforming to the rule regarding the centre of each sub-array –one button press was always correct when the central region of the target contained a shape; the other button press was always correct when the central region of the target did not contain a shape. Once located, participants could use this rule for the response discrimination judgement on the target.

Experiment 3a identified significant gains in RT when training was directed towards the Move centre. This demonstrates the advantage of knowing in advance where the target will appear. No such benefits were observed for training directed towards the Fixate centre however, either when given in isolation (the FT group) or when combined with Move training (the BT group). This was particularly surprising given that it was with the FCN stimuli used in this study that an effect of Fixate training was seen in Experiment 1 (with the accuracy data). Nevertheless, additive benefits of Move and Fixate training *were* found in Experiment 3b: incremental advantages of FT over NT, MT over FT, and BT over MT in the RT analysis. Whilst at first these results seem inconsistent, when one considers the explanation given to account for the findings of Exoeriment 1 (above), understanding the outcome of Experiment 3 is actually quite straightforward. The initial target identification part of the NFC task in Experiment 1 was probably the least demanding conscious perceptual decision required in the whole experiment. Participants were thus relatively quick with NFC stimuli regardless of training. *However*, feature conjunction processing remains the greater difficulty to the visual system by comparison; this is obscured with the NFC task in Experiment 1 because of the disproportionately easy target identification stage, but is apparent in Experiment 3b because finding the target initially requires visual search, lengthening RTs to a similar extent irrespective the search-for target criteria (i.e FC in Exp. 3a or N in Exp. 3b). The remaining discrimination judgement is therefore harder for the NFC task than the FCN, hence NFC yields an advantage of Fixate training, either independently or in concert with Move training. This is consistent with longstanding FIT (Treisman & Gormican, 1988), feature integration processes being effortful and time consuming in comparison to subitisation processes.

Summary of Chapter III

The experiment reported in Chapter III set out to further investigate the outcomes of Experiment 3b, this time recording eye movements. In the context of occulomotor statistics it was seen that MT reduced search times, as expected. Furthermore, Fixate training in concert with Move training (i.e. BT) improved performance further still: gaze durations for correct target responses shortening for the BT group. This is in line with the manual response data of the preceding experiment.

Apportioning visual search and stimulus discrimination into identifiable occulomotor periods also allowed examination of the competitive relationship between the Move and Fixate centres. Did MT prolong the time needed to process the target for the response discrimination judgement, in accordance with the idea that reciprocal inhibition would hamper target processing when instructed where the eyes should move? On the surface there was some evidence in support of this contention: the MT group, being given no compensatory strategy for target processing (i.e. not being informed to reference the middle of the target sub-array) had the largest increase in gaze durations on the target. This was offset by Fixate training, the BT group not showing such an increase. However, caution is necessary when interpreting this effect. It is not clear whether gaze durations increased as a direct result of MT in isolation, hence an alternative argument was put forward. The time constraint for responding in Experiment 4 (4 seconds) was such that Move training allowed participants longer to process the target than their untrained counterparts (by virtue of the fact that the MT group did not first have to find the target). The response discrimination judgement is purposefully difficult, and it is quite likely that the MT group make use of the extra time to complete it –hence longer target gaze durations may be explained without reference to the ‘push-pull’ balance between the Move and Fixate centres. The BT group, despite being directed in Move training, do not linger fixating the target for as long because they make use of the Fixate training strategy. By contrast an effect of practice is evident with the NT group, their gaze durations on the target decrease; this reduction likely reflects the fact that they become more accustomed to the response discrimination judgement given the time pressure to respond correctly once the target has been located.

Summary of Chapter IV

For greater clarity in investigating the relationship between the Move and Fixate centres when training eye movements, the paradigm described in Chapter IV placed two locations in direct competition within the same trial. This was not the case with the paradigm used in the preceding experiments, hence the uncertainty about whether MT can lead to a performance detriment [because of the influence it exerts over the Fixate centre].

The basic paradigm adopted for the three experiments covered in Chapter IV required participants to begin each trial by fixating a centrally located letter contained within a circular array of peripheral characters, one of which was a digit (see Fig. 4.1A). Odd digits (catch trials) required a space bar response; even digits required a different response contingent on the identity of the central letter. Two forms of training provided information either about the location of the peripheral digit in each trial (see Fig. 4.1B), or about a quick way to classify the central letter (four of the letters used were symmetrical, the other four were not). The aim was to relate this training respectively to the Move and Fixate centres of Findlay & Walker's (1999) model.

The main finding from the first set of results presented in Chapter IV, those of Experiment 5, was that the MT group, although having faster search times to find the peripheral target digit, exhibited increased re-inspection durations on the central letter (in a feedback condition). It was suggested that this reflects insufficient processing of the central letter in the first instance, owing to the 'pull' of the Move centre away from the letter at the start of the trial when directed in MT alone. Moreover, this effect appeared to be offset with combined training directed towards the Fixate centre, in concert with Move training; the BT group not needing to re-inspect the central letter for longer prior to responding at the end of a trial.

The rationale behind the next experiment was to examine whether the effect of MT on re-inspection durations reported in Experiment 5 indeed reflected re-checking of the central letter for the purpose of maintaining accuracy. To this end the same paradigm was used but this time the central letter disappeared after the initial period of inspection, offsetting following the same duration as the initial central gaze durations for each group in Experiment 5. The idea was to force a reduction in manual response accuracy for the MT group. The predicted effect did not present in the analysis, accuracy being comparable between groups. However, because an *overall* accuracy reduction in Experiment 6 would be hidden with the omnibus F statistic confined to this experiment, the analysis was repeated incorporating 'Experiment' as a between groups factor (i.e. comparing Exps. 5 and 6). Participants were less accurate in Experiment 6, and although the difference was small (~3%) the effect was significant at the 0.05 α level. Did this reflect the facts that the MT group could not make overt re-fixations, and that the other groups were prohibited from re-checking the central letter using peripheral vision, hence an overall decline in accuracy, irrespective of training group? Alternatively, perhaps the answer is less arcane, and the MT group of Experiment 5 did not really *need* to look back at the central letter, but did so more regularly simply because it was available for re-inspection.

These were two questions addressed in Experiment 7, which used the same design structure but with a gaze contingent display. A gaze-contingent moving-window was tied to the point of fixation, restricting viewing to a spatially restricted area around the current point of regard. This technique eliminated any reliance upon peripheral vision. However, although the MT group had the biggest increase in re-inspection durations in Experiment 7, the effect failed to replicate. Manual response accuracy did once more return to the original levels seen in Experiment 5 however.

Given that the number of re-fixations on the letter were less numerous in Experiment 7 (where it is not possible to look back at the letter using peripheral vision), it is unlikely that the lower accuracy of all groups in Experiment 6 was due to re-checking via peripheral vision; if it were one would expect re-fixations to *increase* with the gaze contingent display. Moreover, because less re-fixations were made in Experiment 7, it is less likely that the alternative account offered above (that the MT group looked back for longer in Experiment 5 just because they could) applies. It was possible to re-fixate the letter in Experiment 7, but the MT group did not do so as often. Eliminating the ability to re-fixate the letter in itself probably reduced accuracy in Experiment 6, but the fact that re-fixations were not as frequent in Experiment 7 suggests that there is something about the gaze contingent display which aids the initial processing of the central letter.

This leads on to the two accounts that were favoured when concluding Chapter IV. First, given that initial central gaze durations never differed between groups throughout Chapter IV, it was proposed that premature covert shifts of attention accounted for the increased re-inspection durations in Experiment 5. This conclusion entails the argument that eye movement training directed at the Move centre is necessary but not sufficient to hinder the initial processing of the central letter. For such a detriment to arise it appears that *both* bottom up stimulus features *and* top down MT need to influence the eye movement system simultaneously. The peripheral array was always concurrently visible in Experiment 5, hence this explanation accounts for the results. The second suggestion proposed when concluding Chapter IV however, was necessary to explain why no related negative consequences ensued for the MT group in Experiment 6 –here, the peripheral array was also currently visible throughout, yet there appeared no performance detriment specific to the MT group. I suggest that when compelled by task demands, the natural 'flip-flop' gating mechanisms for maintaining equilibrium between the Move and Fixate centres can be overridden and mediated by voluntary control. There is previous research which supports such a standpoint (Coeckelbergh et al., 2002; Mosimann et al., 2004; Tse et al., 2002), and Voluntary Control at Level 5 in Findlay & Walker's (1999) model could account for the MT group in Experiment 6 strategically adapting to extract the required information from the centre at the start of the trial, thereby not being drawn away towards the peripheral items too soon.

It is conceded that additional research (as outlined at the end of Chapter IV) would be necessary to confirm the above conclusions, being based upon null effects as they are; nevertheless, this way of rationalising the data seems the most logical and parsimonious for bringing the results in Chapter IV to a close in the context of a PhD thesis.

Summary of Chapter V

One of the practical motivations behind the work undertaken for this thesis was to relate the training induced Move–Fixate competition hypothesis to hazard perception in drivers. Indeed this was one of the aims proposed for the '+3 ESRC competition studentship' which has funded my PhD studies. Hence Experiment 8 set out to investigate whether a visual search strategy which encouraged eye movements (similar to the UK dept. for transport Think Bike! campaign, 2008a) gave any indication of leading to errors comparable to Look-But-Fail-To-See –.

Video clips of driving scenarios as described by Jackson, Chapman & Crundall (2008) were used in Experiment 8. Participants were required to watch the clips, and respond when they thought they detected a hazard (defined as an event which would require evasive action to be taken if actually driving) –this paused the clip and their hazard detection accuracy was gauged, as well as monitoring the reaction time delay between the hazard onset and the space bar response. Four experimental groups were tested with this procedure, the difference between them being that variants of an additional secondary task were carried out while viewing the scenes for potential danger. The MT group here were required to follow a left-centre-right-centre… etc scanpath throughout each clip; the BT group were required to follow the same scanpath but to look for longer at each spatial region before moving their eyes to the next (3 seconds as opposed to 1); a 'Spatial' Control group was also used (SC), being required to speak aloud "left-centre-right-centre" (and so on…) while they completed the primary hazard detection task; and finally, an untrained control group, having no secondary task, were also tested for baseline comparison data.

No effects of MT were observed in Experiment 8. The only finding of note was that the SC group had longer RTs from hazard onset (as compared to the untrained control group). Why was this?

One reason that MT, as operationalised here, did not give rise to the predicted performance detriment may have been that the eye movement sequence did not focus enough on moving the eyes quickly and continuously. Alternatively, despite the effort to make the task a realistic imitation of hazard perception on the road, there are several points surrounding the difference between Experiment 8 and actual driving. For one, large amplitude head-movements often accompany eye movements when driving a vehicle. Whether the premises of Findlay & Walker's (1999) model apply to movements of the head, and could therefore present a problem when advising drivers to scan the roadway vigilantly, remains an interesting avenue for further research. It is also noted that because a vehicle was not being controlled, and there were no tangible consequences of having an 'accident' in the laboratory setting, that the experiment may not have captured the elements of hazard perception and eye movements as they apply in the 'real-world'. The absence of eye movement recordings makes it difficult to draw conclusions with certainty (perhaps detection failures would have been present in oculomotor statistics), but on the surface however it appears that eye movement training similar to the Think Bike campaign (DfT, 2008a) does not necessarily pose a problem for accident liability when driving.

From this position, the question then arises as to whether participants were using any compensatory strategy to minimise the influence of bias in the Move centre brought about by MT. It was argued in Experiment 6 that such voluntary control over eye movements may be possible, strategically extracting the required information when fixating, overriding the 'pull' of the Move centre according to task demands. It is possible that this played a role with Experiment 8.

Lastly, the fact that the SC group did show an extension in RTs required explanation. It was suggested that the spatial referencing component of the secondary verbal task the SC group carried out had an interfering effect on hazard perception skills. It is conceivable that the reciprocal relationship between the Move and Fixate centres can be regulated up to a point, if necessary to meet task requirements, but that this modulation becomes more difficult when having to verbally express words which are intrinsically linked to spatial locations. This idea is consistent with well established models of working memory and visiospatial interference (e.g. Baddeley & Hitch, 1974; Logie, Zucco, & Baddeley, 1990). If correct, the interpretation has implications for the use of mobile telephones (even hands-free) when driving, because conversations could sometimes lead the driver to access information in the spatial memory domain (clearly further research would be needed however to elaborate upon this speculation). It has previously been shown that conversations with people in the car do not necessarily pose such a problem because passengers regulate their utterances according to the demands of the roadway, being present in the vehicle to appreciate potential risks (Crundall et al., 2005).

6.3. Implications for Findlay & Walker's model and further research

One general question, important for all the experiments conducted herein, is whether the methodology employed for this thesis correctly denotes the antagonistic relationship between saccades and fixations as conceptualised by Findlay & Walker (1999). Admittedly, the work I have described is quite different from the low level influences on eye movements to which Findlay & Walker refer as evidence for their theoretical framework. However, this partly reflects the overall goals of the experiments: to shed greater light on top down influences, because The Model is 'bottom heavy'. By definition then, the research, and its outcomes, will be different. Nevertheless, because The Model is hierarchical, and competition between the WHERE and WHEN pathways from the upper levels culminates in Move and Fixate centres respectively, there is still good reason to believe that (at least with paradigm of Experiments 5-7 where two areas compete for attention within the same trial) the antagonistic relationship between the Move and Fixate centres is being tapped into.

This notwithstanding, there are some features of the results which have been presented that sufficiently depart from the understanding of eye movement control offered by Findlay & Walker (1999) to warrant further justification. Mainly, these concern the fact that individual fixations and saccades were not specifically studied (e.g. saccade latencies as with the Gap Effect [cf. Kingstone & Klein, 1993]; and landing points as with reading research [cf. Reichle et al., 2003] etc.), and that affects on parametric mean fixation durations were rare. These issues were addressed initially in Chapter II and then later in Chapter III.

To begin with, Fixate training, as implemented with the square and circle stimuli of the first two chapters, did seem to reduce processing load. In Chapter I it reduced the time needed (manual RTs) to extract the required information from target stimuli, and in Chapter II it was shown that this could be attributed to a greater economy of each fixation, the BT group, although having similar fixation durations to the MT group, requiring less fixations overall to apprehend the right information for the target discrimination judgement. Although slightly different from the fixation gating mechanism as conceived in The Model, these results accord well with evidence cited by Findlay & Walker for the *cognitive processing* channel in the WHEN pathway. Gould (1973) identified a decrease in processing time for stimuli which remain unaltered when informational load is decreased. To elaborate: when scanning for a target letter, fixation durations increase with an increase in set size of potential targets memorised. The results of Experiment 4 likewise suggest that a reduction in processing load can affects fixations; however, it appears than when the task relies more heavily on top down cognitive resources, it is not necessarily fixation durations per se which are affected. Fixate training seemed to improve the efficiency of each fixation (*less* target fixations being required by the BT group), while individual fixation durations remained constant. Maybe the effects revealed when harnessing resources further up the hierarchy are more likely to be borne out in *multiple* fixations aggregated across stimulus inspection.

The reason individual saccades were not studied is more transparent. When training people where to look in applied settings, advice (usually) cannot be bound by strict regularities, since the domain in which it will be used is often defined more by variance than by stability. Sports, driving, medical practices etc., all have facets which rely on visual skill in a changing environment, unlikely to be identical from one situation to the next. It would be interesting to study whether a training phase requiring strict adherence to executing saccades towards exact spatial locations (more akin to visuomotor and perceptual learning, landing points becoming more and more precise with extended practice over time) magnifies phenomena such as Inattentional Blindness (Mack & Rock, 1998) and Change Blindness (Simons, 2000) in a test phase. However, because recommendations on eye movements for the real world most often must be general, and because the aim was to investigate the top down implementation of such strategies, it is believed that Move training here is as specific as it could be while holding these objectives in mind. Similarly, it is the overall pattern of eye movements, and therefore collective oculomotor statistics which better represent the range of processes involved in complex visual cognition. Given the aims of the thesis, a balance was struck between greater control but loss of relevance to everyday settings, and less control but loss of rigour concerning the parameters of individual fixations and saccades. Seeing as The Model is already 'bottom heavy', the methodology employed herein seems a suitable trade-off to meet with the intended goals.

Also concerning Move training and its relevance to Findlay & Walker's (1999) model, one may ask, which particular feature of the framework (see Fig. 1.1) do the MT sequences I have used apply to? In all likelihood *Spatial Decision* plays a role, in choosing to move the eyes to the next location dictated by the MT sequence. To some extent this may also interact with *Search Decision*, because features corresponding to the target template are also held in mind, whether they be a conjunction of features, as with Experiments 1-4, or the component lines constituting a digit, as with Experiments 5-7. The degree to which *Search Decision* is important for the tasks used in this thesis could easily be investigated by varying the probability that target occurrence conforms to the MT contingency. In all the studies carried out here, target presentation was 100% predictable; the MT sequences never broke, and the exact location to focus on was specified. Both of these features of target presentation could be varied probabilistically, diverging from the suggested eye movement training to different degrees. Changing the predictability of the underlying MT pattern would have the twofold advantage of revealing whether participants immediately notice that target presentation does not strictly adhere to the MT strategy (thereby shedding light upon the involvement of *Search Decision* and the sub-ordinate process of *Search Selection*), as well as uncovering how constrained the training needs to be to benefit visual search. This last point would also address more directly the problem of uncertainty in the environment in which eye movement training regimes are to be of use.

A final point about the meaning of the results contained in this thesis for Findlay & Walker's (1999) model. Feedback was manipulated, initially in Experiment 4 and thereafter in Experiments 5-7. The rationale behind this manipulation was to try and encourage participants to move their eyes as specified by MT and pay less attention when inspecting the area to which they were guided. Thus, when feedback was withdrawn it was hoped that eye movements would follow the designated pattern of target presentation, but that participants would focus less on scrutinising the target properly to identify the correct response. If this rationale is correct then it should emulate the idea of quick visual scanning, but reduced information uptake from fixations owing to increased activity in the Move centre. In fact, this was not the case. If anything Move trained participant were better without feedback. It was argued when discussing Experiment 5 that the provision of feedback may cause a processing bottleneck. While trying to remember the present and upcoming spatial location of the peripheral number targets, participants return to the centre of the circular array for the next trial. As they prepare to discern the correct response to the new central letter, the brief flash of the feedback mask in the inter-trial-interval may overload resources which are already stretched to near capacity. Thus, processing of the feedback mask to assess the accuracy of the previous response spills over into the next trial when commencing the initial discrimination with the central letter; these three factors (memory for the sequence of target locations, evaluating the feedback mask, and processing the new central letter) may well cause a bottleneck. Moreover, due to the 'pull' of the Move centre when directed in MT it is the letter discrimination judgement which suffers, participants making a premature shift of covert attention towards the peripheral target too early. When a barely distinguishable transient grey mask is presented instead, this processing bottleneck does not arise; hence re-inspection durations are longer for the MT group in the feedback condition but not the no feedback condition. Likewise, the affect of a feedback-related processing bottleneck is offset for the BT group because they have the symmetrical strategy to rely on for the central letter.

To investigate the precise role feedback plays further, the no feedback condition of Experiment 7 was changed so that an equiluminant –purple or green –, but none informative (i.e. providing no information about response accuracy), feedback mask was presented instead. The number of re-inspections was larger in this non-informative feedback condition, but this effect was not specific to the MT group, all groups looking back at the central letter more frequently when an equiluminant mask was presented at random. It may be that the visual disruption of providing feedback is fundamental to the effect, and perhaps that participants find it difficult not to attempt to evaluate the meaning of non-informative feedback in relation to their responses. Using non-informative feedback masks seemed to make participants more cautious about responding correctly. How ever feedback effects the implementation of eye movement training as studied here, it is apparent that, at best, the provision of feedback is of no benefit.

It was suggested when discussing the results of Experiment 5 (section 4.1.3) that Event Related Potentials (ERP) would be a good method for establishing whether the MT group [of Experiment 5] prefer to internalise error monitoring, indeed whether feedback is of little advantage per se when training eye movements. Holroyd, Hajcak, & Larsen (2006) identified a frontal lobe ERP component associated with evaluating the outcome of decisions even when feedback is neutral –feedback Error Related Negativity (fERN) is linked to awareness of mistakes. It may be that Move trained participants generate fERN more readily because they prefer to regulate error monitoring internally (there is a response-locked component of ERN, occurring independently of feedback, which would also support this [cf. Hajcak & Simons, 2008]). If this is the case it would be a useful revision for Findlay & Walker's model (1999), and its ability to incorporate plasticity of the visual system via self learning. Whether the results are similar for feedback presented in the auditory modality would also be of interest; though one suspects auditory feedback would produce comparable effects based on previous findings of crossmodal integration, auditory input effecting eye movement parameters (Arndt & Colonius, 2003; Morein-Zamir & Kingstone, 2006; Rolfs, Engbert, & Kliegl, 2004).

Moreover, genuine detection failures, even when objects are fixated, could be examined more thoroughly with more invasive techniques such as ERPs. Rahman & Sommer (2008) have demonstrated early ERP components associated with object recognition; presumably these would not occur when an object is looked at but goes unnoticed? (Although one acknowledges that inherent practical issues, not least measurement sensitivity, would be problematic when combining eye tracking with such neuroscientific methods).

On the issue of learning, whether self monitored or not, there are other avenues worthy of additional research not specifically studied in this thesis. It is recognised that the approach taken here does not focus upon typical conceptions of perceptual learning, and the difference between learning and implementing strategic advice has been alluded to throughout. The aim was to evaluate the latter, with the supplementary hypothesis that in some circumstances advice which encourages eye *movements* could have undesirable consequences. Nevertheless, it is worth discussing the connection between strategic advice and learning. Certainly, as reviewed in the General Introduction (Chapter I; section 1.3), there are occasions where visual training can be useful when learning is established through practice – perceptual learning with video games (Shapiro & Raymond, 1989), improving visual acuity and reading speed in macular degeneration (Seiple et al., 2005), and accelerating skill acquisition in drivers (Chapman et al., 2002; Pradhan et al., 2006), are some examples. However, the contention is that when training of this type commences, it is at first like adopting strategies as used in this thesis. This may be unhelpful firstly because, until learning is consolidated (becoming automated in Level 4 processes of The Model), putting strategies into practice requires volition and executive control. Thus, adhering to the tenets of training may conflict with other task demands in the first instance, making performance worse before it gets better. Secondly, we have seen that there may be some truth in the idea that training people where to look only can impair information uptake when fixating. Training may lead to improvements, but these two aspects of learning along the way may be problematic when developing training protocols for use in applied settings. This is particularly true because advice made available to the public is often condensed and generic, and people are unlikely to go away and practice it under the precise conditions in which training benefits are found. Nevertheless, further investigations assessing the point at which learning plateaus in different contexts, possibly progressing from unhelpful to helpful, would doubtless be of use. One could incorporate with this evaluation of the durability of learning, re-assessing trainees following different time periods. In the case of the experiments conducted for this thesis, it would be of interest to see how long-lasting memory of the training strategies is, and whether untrained participants are better at re-test than a new naïve group. Which facets of visual skill are most receptive to training, and whether previous learning or knowledge of training contingencies can be cued by the context for which they apply, are research questions still with a lot of scope for future advancements.

Lastly, one aspect of Findlay & Walker's (1999) model that I have not dwelt upon is their conception of a saliency map. At Level 2 peak activity in the saliency map, determined by input from the levels above it, stipulates the next location the eyes move to. This is a winner-take-all process; saccades are ballistic, their amplitude and direction being planned in parallel and in advance. In many ways Itti & Koch's (2000; 2001) computational model of saliency is comparable, and may be thought of as a fully delineated and workable saliency map model. However, there are some facets of saliency argued by Findlay & Walker which do not feature in the Saliency Map Model. Itti & Koch focus primarily (though not exclusively) on bottom up stimulus driven salience, while Findlay & Walker allow for a greater degree of top down modulation within the saliency map. Despite the terminology '*Intrinsic' Salience,* Findlay & Walker suggest this component of their model can be influenced by learning. This raises the question of whether *Intrinsic Salience* should be re-named or sub-divided into separate channels, one which is 'hardwired' lower down the hierarchy, dealing with the classical idea of saliency as centre-surround differences in low level visual input, and one which is plastic further up the hierarchy, dealing with learned priority for certain visual events and stimulus classes over others.

Foulsham, Barton, Kingstone, Dewhurst, & Underwood (in press) have examined the influence of saliency in a patient with visual agnosia. This neurological disorder is characterised by severely impaired object recognition. The relevance to *Intrinsic Salience* and learned priority is that when top down object recognition processes are disrupted or absent, the eyes should be guided predominantly by low level bottom up input; therefore in cases where normal individuals show evidence of top down influences on visual search behaviour, eye movements of the agnosic should be closer to those predicted by the saliency algorithm of Itti & Koch (2000). This hypothesis was supported by Foulsham et al.; unimpaired individuals being able to override low level visual saliency and direct their eye movements straight towards search targets in naturalistic scenes, the eye movements of an agnosic case study however (patient CH) being a much closer match to model computed salience.

Clearly there is a difference between intrinsic salience in terms of bottom up features, and intrinsic salience in terms of learned priorities. In unimpaired individuals it has been argued that attention capture is dominated by top down guidance (Chen & Zelinsky, 2006). Moreover, some things may not be salient in terms of Itti & Koch's (2000) model, but may be thought of as intrinsically salient because we have learned to devote attentional resources towards them, it being biologically adaptive so to do. Point-light stimuli arranged at the joints of a moving person for example is enough to convey a compelling percept of human form, even though the visual information is much impoverished (Neri, Morrone, & Burr, 1998). Downing, Bray, Rogers, & Childs (2004) have shown that the human body may also be prioritised for attentional selection. Further, attentional facilitation is evident for fear-relevant emotionally provocative stimuli –snakes, spiders, and the like (Öhman, Flykt, & Esteves, 2001). With the above examples, stimuli need not necessarily be salient in terms of brightness, contrast, luminance etc. –the feature maps used to define low level visual salience –but the fact that they capture attention makes sense for evolutionary reasons.

Other modes of attentional deployment may be experience and context specific; we have already seen evidence that the eye movements of experts differ from those of the novice, in domains as diverse as reading (e.g. Underwood, Hubbard, & Wilkinson, 1990), driving (e.g.Crundall & Underwood, 1998), rifle shooting (e.g. Di Russo, Pitzalis, Aprile, & Spinelli, 2005), and cricket (e.g. Land & McLeod, 2000). Experiential affects on eye guidance to certain stimulus types seems much less like physically intrinsic salience and much more like perceptual and visuomotor learning.

From the above discussion of *intrinsic salience* it seems that Findlay & Walker's (1999) terminology is a little vague, and does not distinguish between intuitive differences in how we may understand the idea of intrinsic salience. A three-way subdivision feeding into the Move centre may improve clarity. *Physical Salience,* as defined in Itti & Koch's algorithm, could be one component; *Evolutionary Significance* –biologically adaptive attentional priority for stimuli such as human bodies, snakes, spiders etc. –could be another; finally, *Learned Priority* could be the third, a feature of The Model allowing for experienced-based and context-dependent changes in eye movements. Work on the firing properties of neurons supports the idea of topographically mapped salience which can be modified according to stimulus relevance: Fecteau & Munoz (2006) also use the term Priority to describe the fact that stimulus elicited salience can be adjusted for consistency with behavioural goals.

If one accepts the above classifications and accompanying terminology the question then arises: are the different salience categories immune to changes in eye movements with training? Whether implementing top down strategic advice, or undergoing more gradual training equivalent to perceptual and visuomotor learning, it is conceivable that certain stimulus types will still benefit from enhanced attentional weightings, despite training-related oculomotor changes. This may differ depending on the strength of the training effect, the importance of the stimulus class, and the extent of previous learning.

6.4. Synopsis - Final Comments

Despite what we have learned from the experiments comprising this thesis there is still much to be gained from continued research into eye movement training for complex visual tasks. The take home message is that visual training protocols could benefit from concentrating more upon strategies to improve the apprehension of detail when fixating. For intuitive reasons, eye movement training all too often only emphasises *where* people should look. Therefore a caveat is added to these final comments: in particular constrained circumstances performance could even suffer following training which encourages visual scanning, because there may be a cost in terms of less than optimal information acquisition during fixations. Even though this effect may be subtle under laboratory testing conditions, this does not undermine its significance to applied areas where visual detection failures can be of paramount importance. Recommendations for the future therefore stem from participant groups who underwent combined training, being given strategies for information uptake when fixating *as well as* being advised where to look to locate target stimuli. Combined Move and Fixate training may give rise to additive performance gains (faster visual search *and* more efficient stimulus discrimination), and offset detection failures associated with Move training alone.

However, it should be pointed out once more that the author of this thesis is aware of the difficulty of adapting training strategies as operationalised herein for use in real word applied contexts. With the majority of experiments presented in this document stimulus presentation was precisely controlled. The location targets would appear in from one trial to the next was known by the experimenter, and this was the basis of training directed towards the Move centre, participants being guided in visual search by advance knowledge of where the target would be. Similarly, uniformity in stimulus composition formed the basis of training directed towards the Fixate centre; stimuli were designed with contingencies to assist with their classification in mind. Clearly, in everyday settings we do not have the benefit of such advanced knowledge; we do not know with surety exactly where important events will transpire, or the exact form certain stimulus classes will take. Nevertheless, with regard to location-based Move training, although we do not know in absolute terms where to advise people to look, we can often have a very good idea. Probability based observational studies, recording likely locations for the occurrence of important visual events in different domains, would improve the ability to prescribe location based (Move) training further still. With regard to Fixate training, although stimulus-response mappings are not so easily simplified outside of the laboratory, it is re-iterated that in cases where attention to redundant detail can be eliminated, this should be strived for. Where condensing information is not feasible, implementing Fixate training may be as simple as advising people to "look for longer". For instance, visual scanning interventions in cases of hemispatial neglect, a disorder arising from neurological injury characterised by impaired attention to the left of space, often have only limited success (Karnath, Milner, & Vallar, 2002). Perhaps as well as merely encouraging eye movements to the left side of space, neglect patients should also be advised to remain fixated on the left for extended intervals, making use of voluntary control mechanisms over eye movements.

The implications of looking but not seeing (cf. Exp. 5, and cf. Brown, 2002 LBFTS; Inattentional Blindness, Mack & Rock, 1998), or looking for longer than is strictly necessary (cf. Exp. 4) are far reaching, having practical implications in many areas, for example, in the military, playing chess, fossil finding, proof reading, etc.

Indeed magicians have been shown to make use of Inattentional Blindness phenomena, misdirecting attention so that people fail to notice things occurring at the point of fixation (Kuhn, Tatler, Findlay, & Cole, 2008). The specificity of training as employed here does not in itself preclude its advantages for a range of applied scenarios, but it does suggest that the largest training gains would arise from a wide variety of tailored schedules for particular tasks. Nevertheless, because training as implemented here is the utilisation of *strategic advice* for visual search and stimulus discrimination, time consuming perceptual and visuomotor learning processes could potentially be bypassed.

7. References

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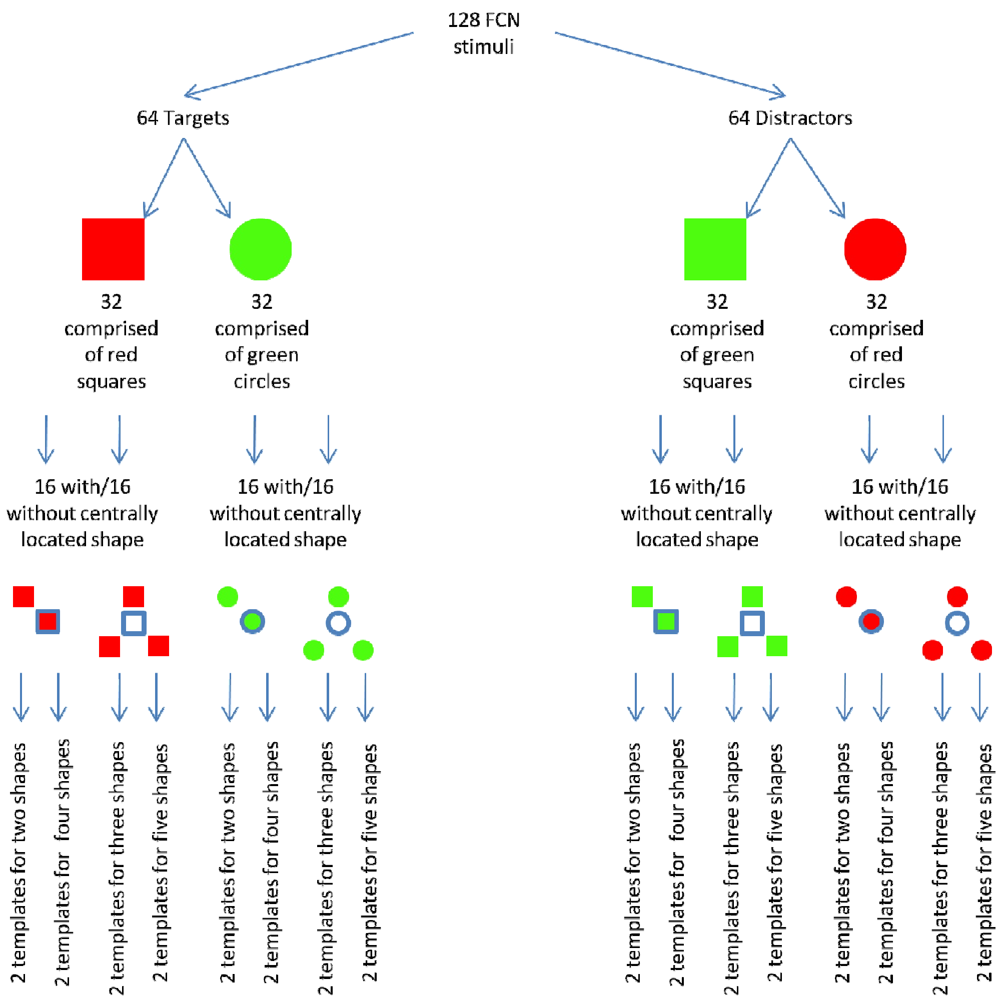
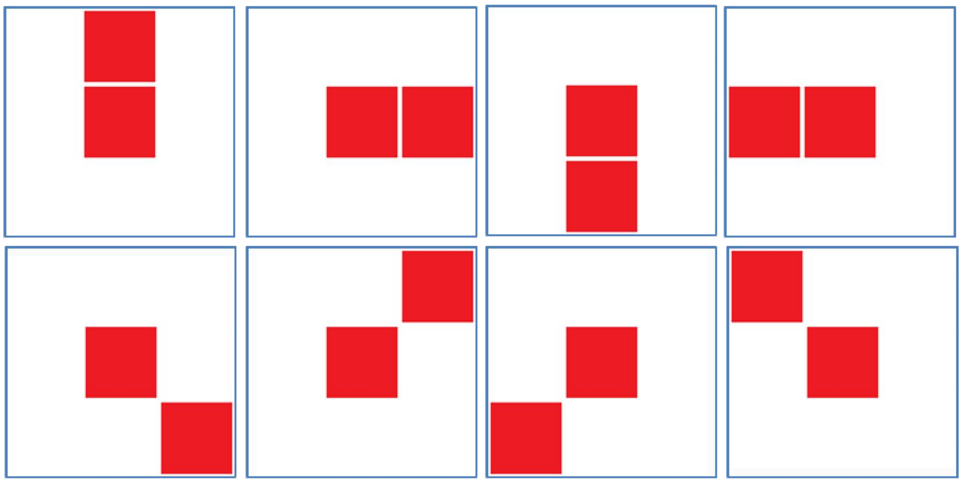
8. Appendices

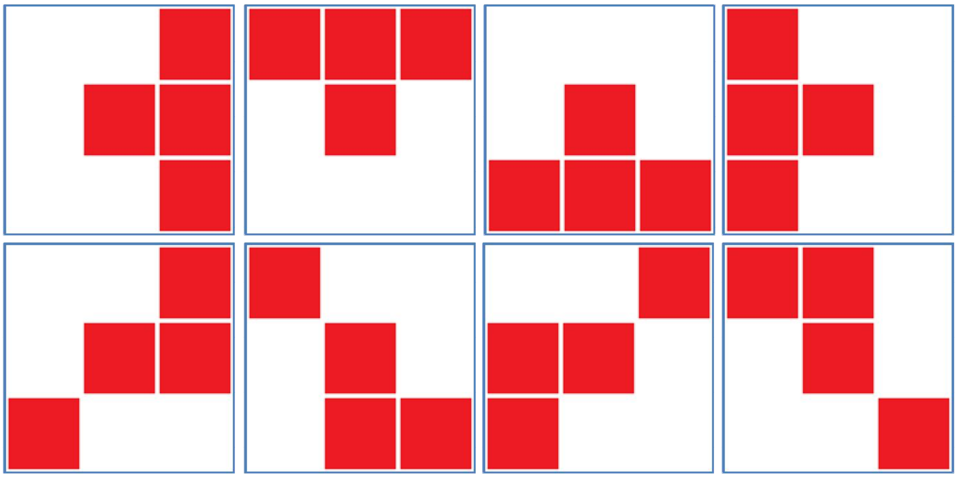
8.1. Stimuli - Experiments 1 – 4

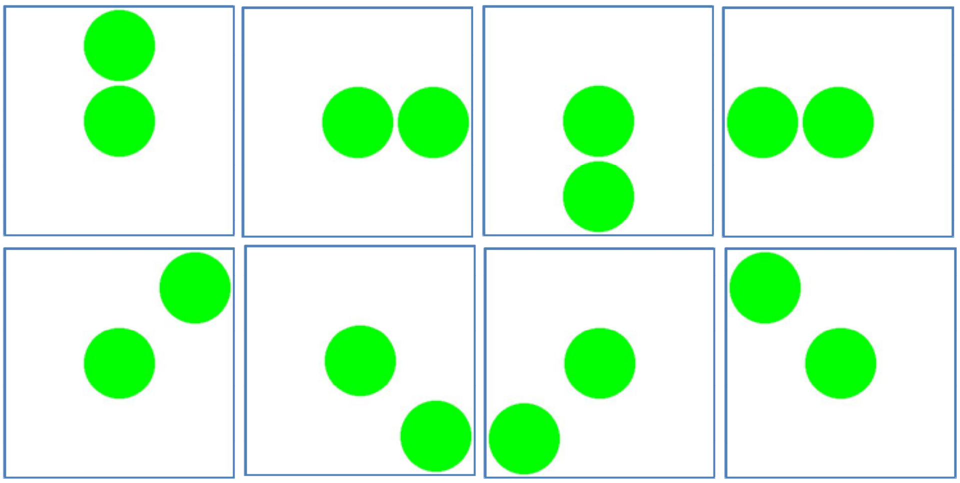
8.1.1. FCN sub-arrays

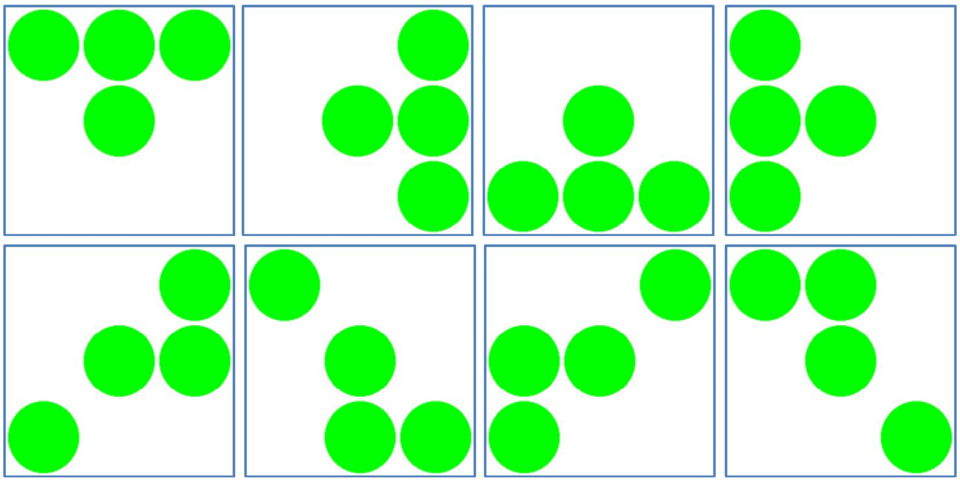


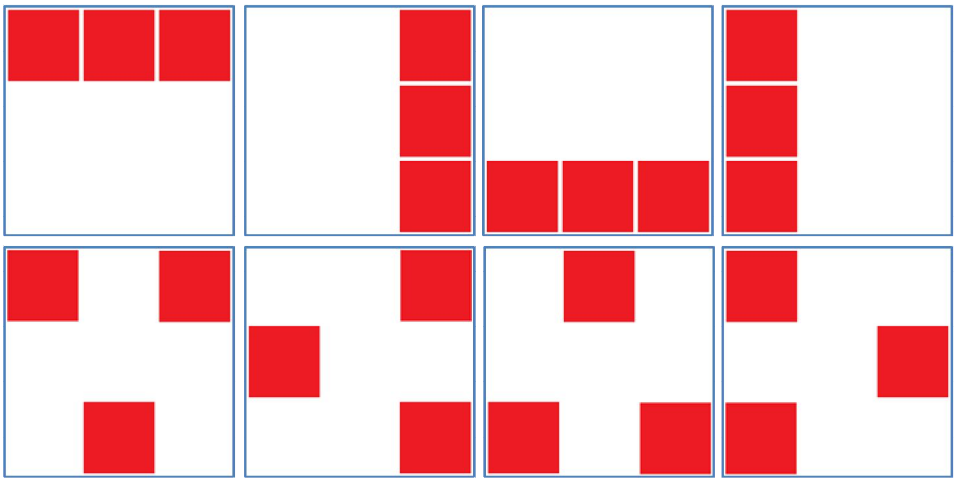
Target Templates: Grouped by row, rotated through 360°

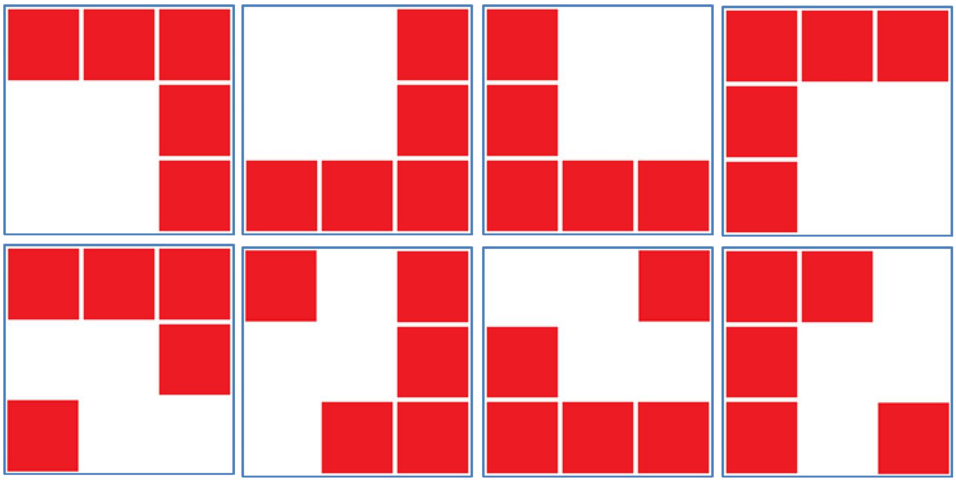


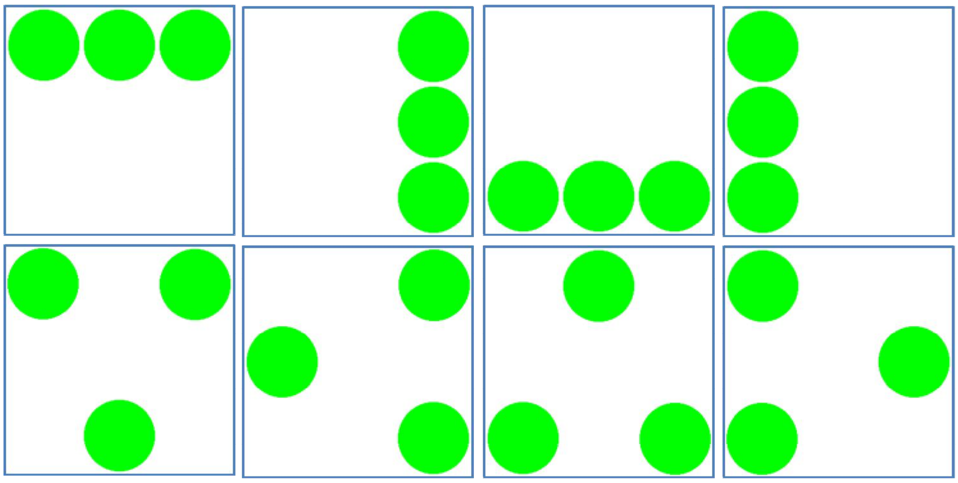


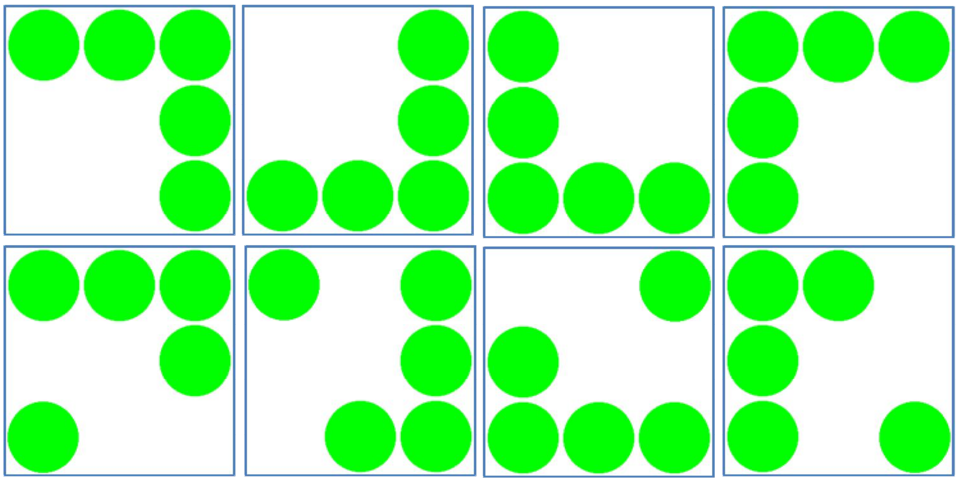




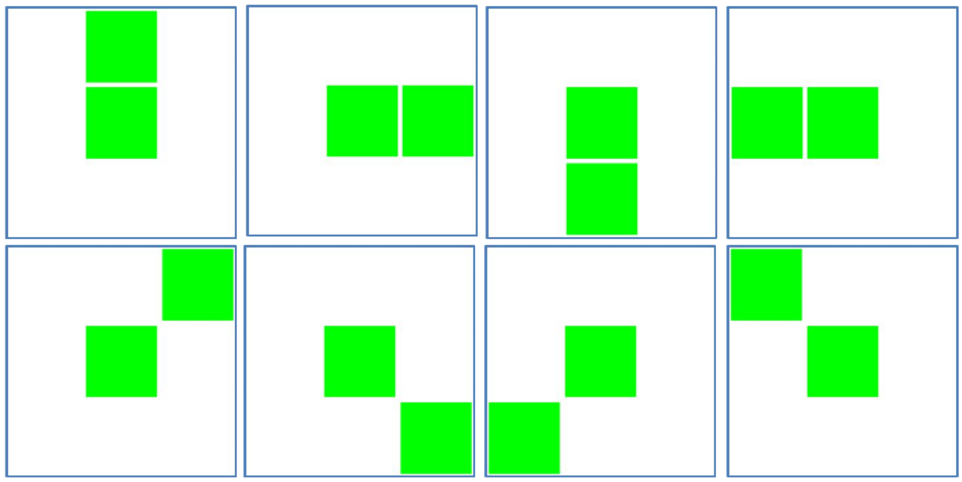


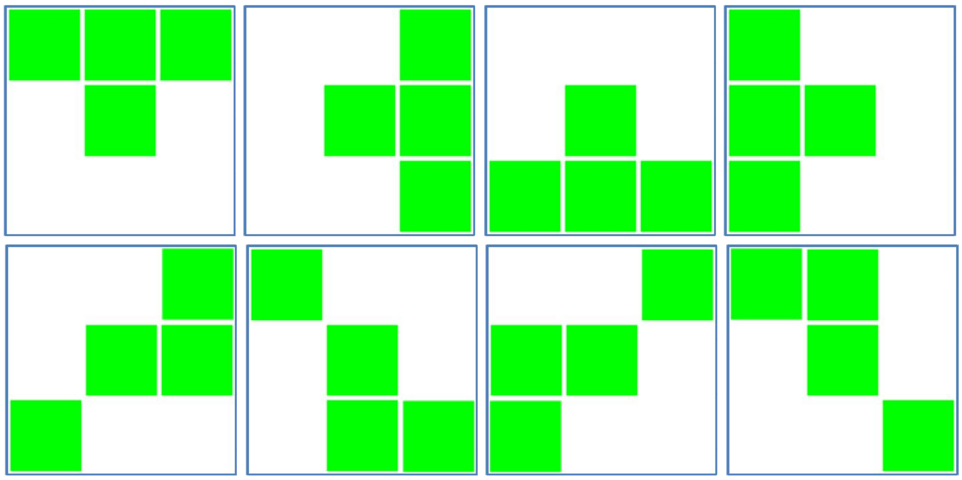


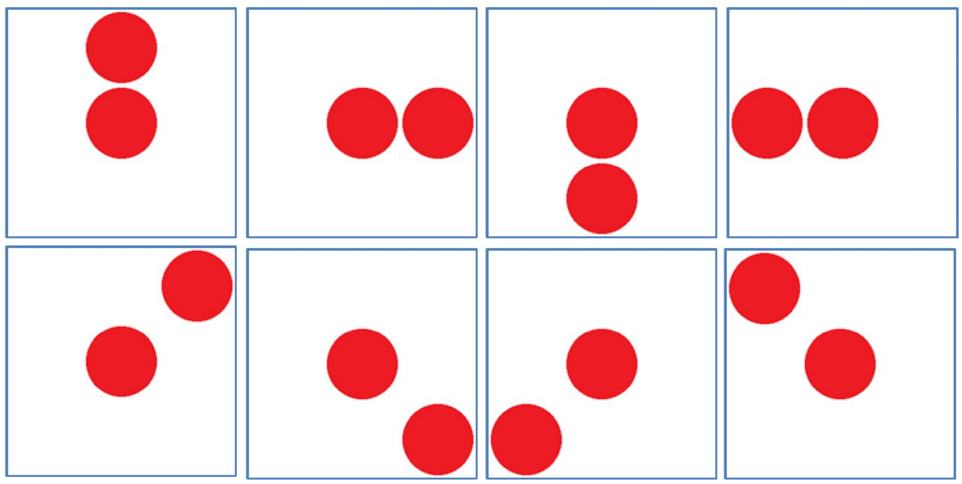


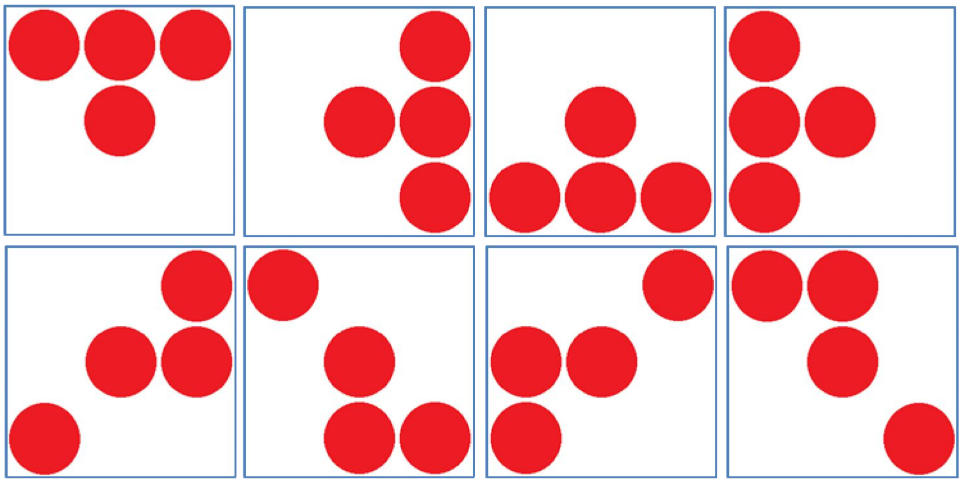


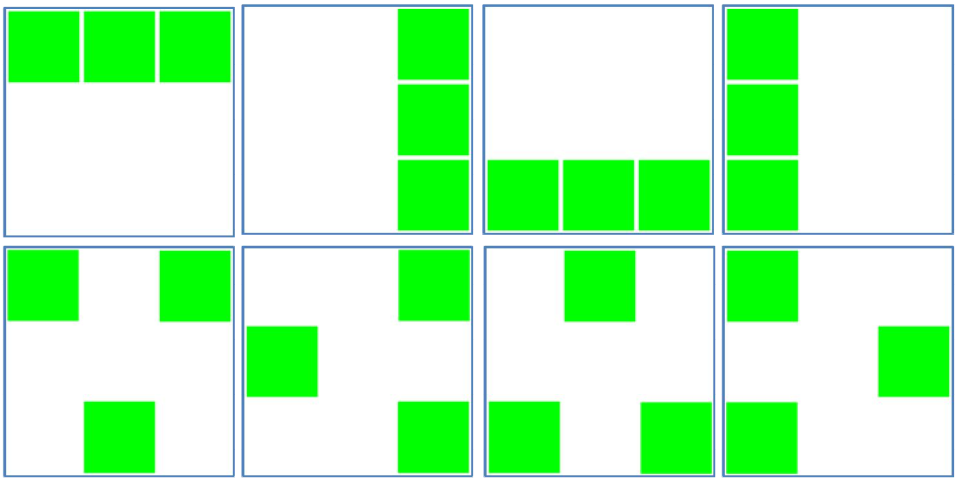
Distractor Templates: Grouped by row, rotated through 360°

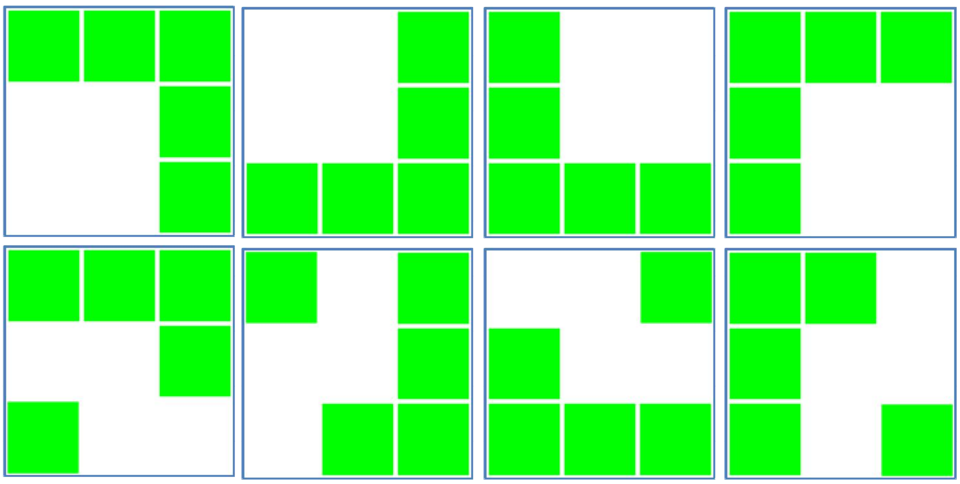


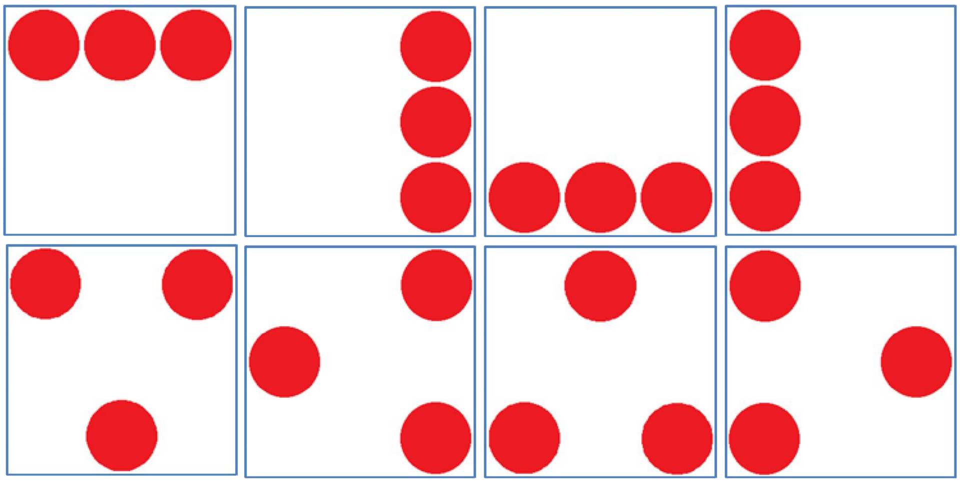


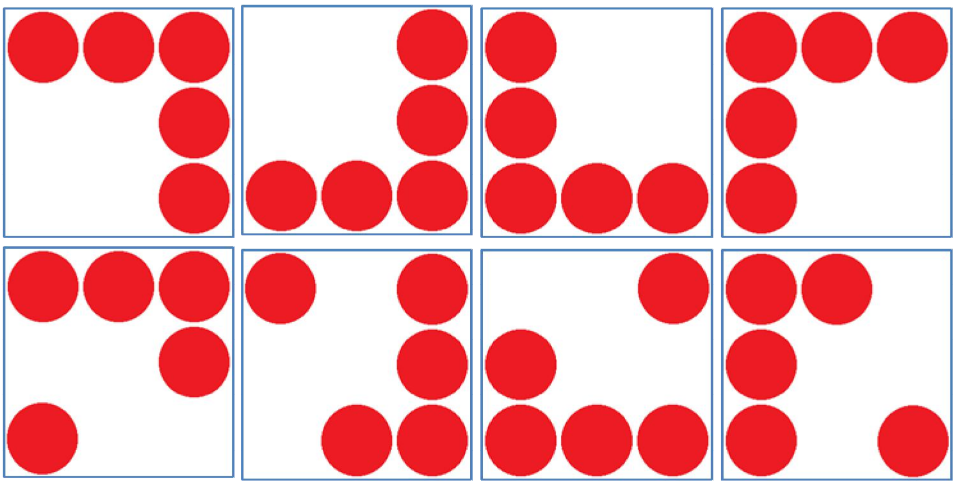




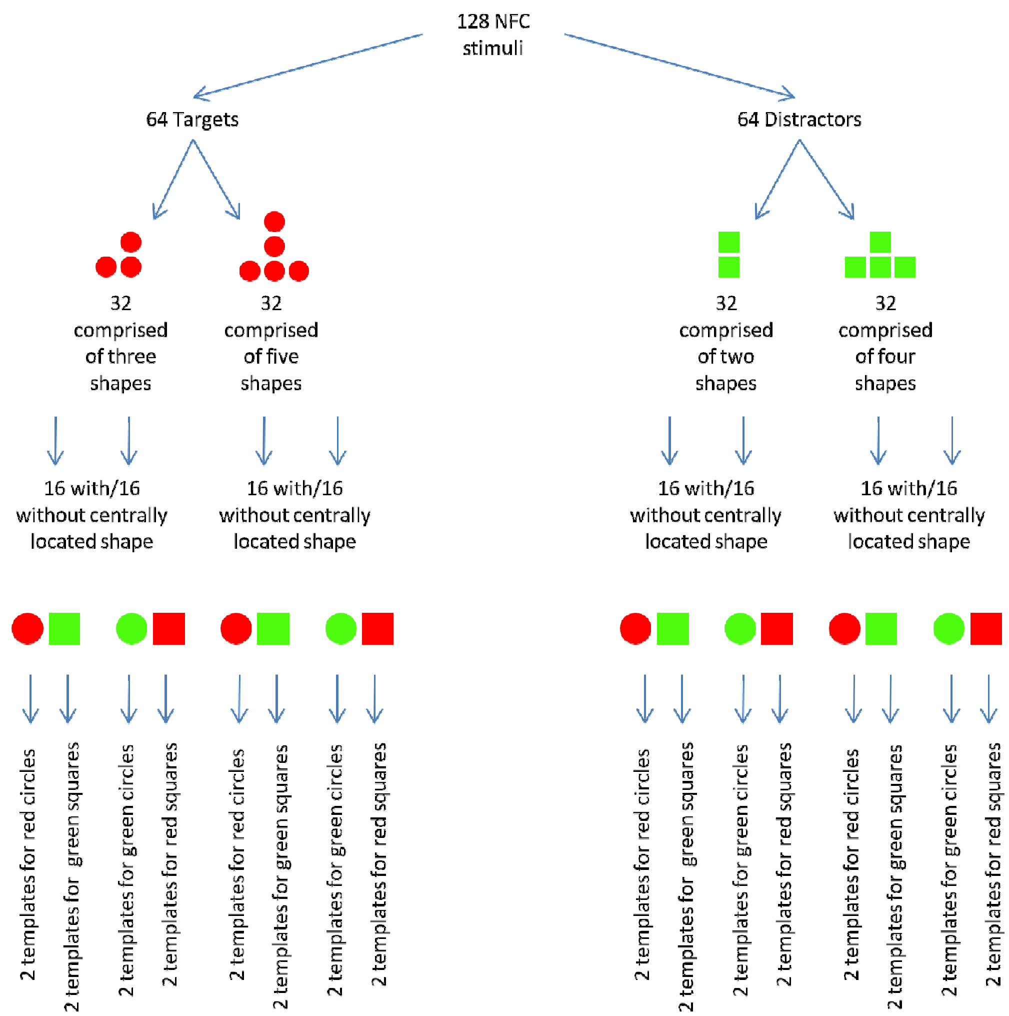




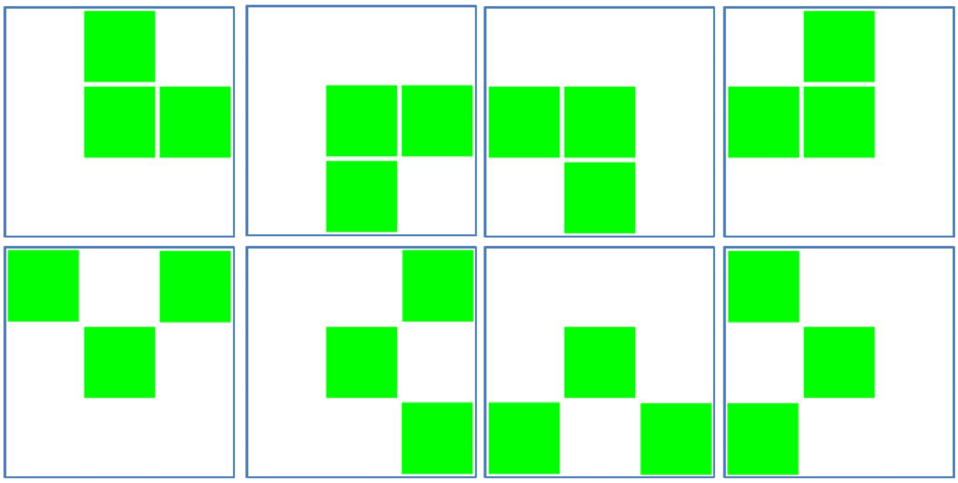


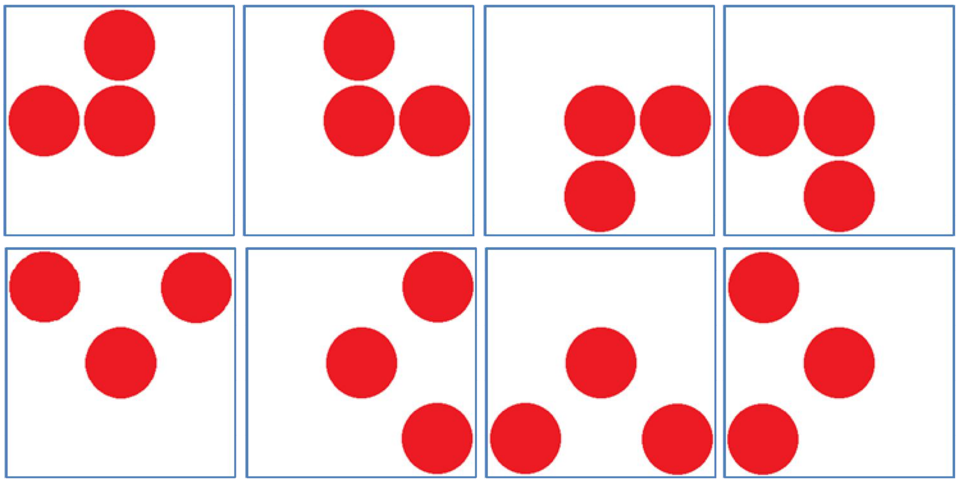


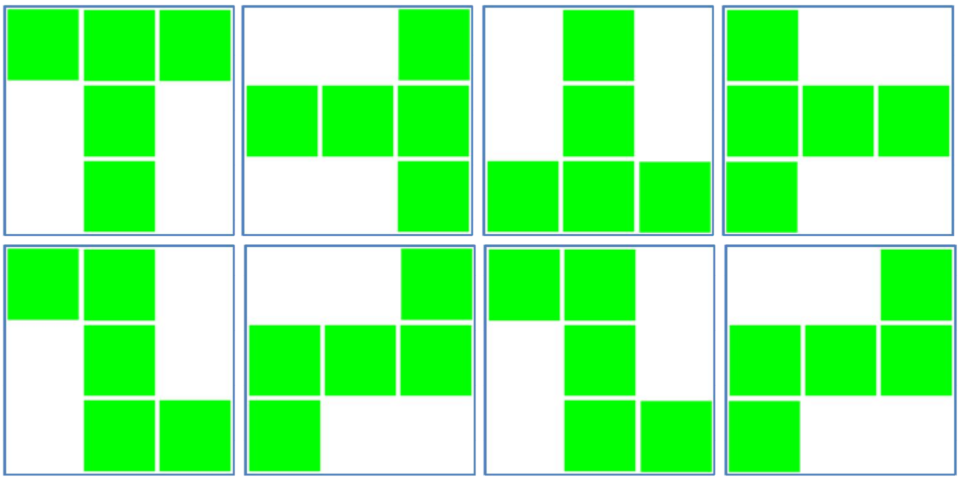
8.1.2. NFC sub-arrays

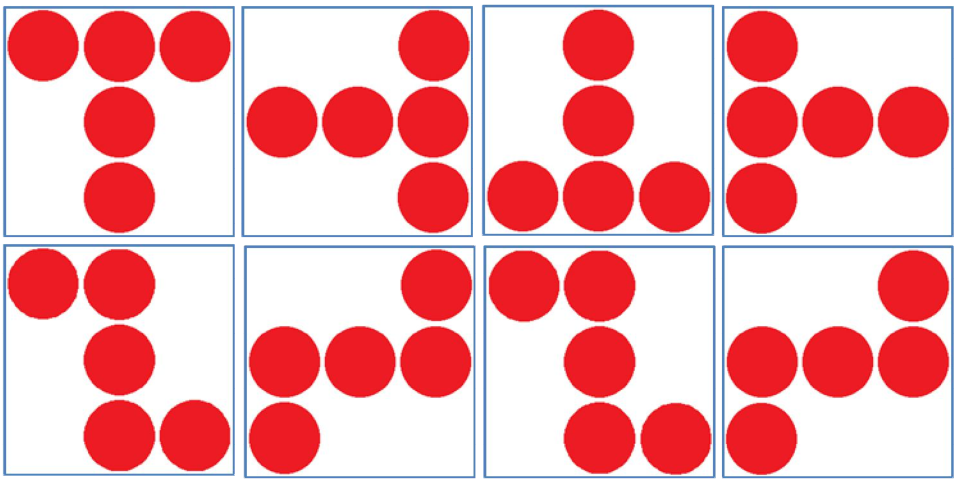


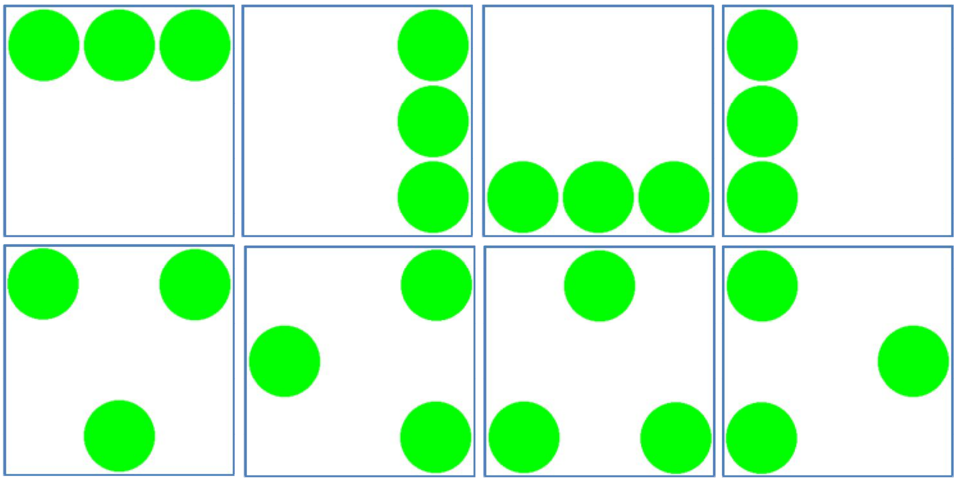
Target Templates: Grouped by row, rotated through 360°

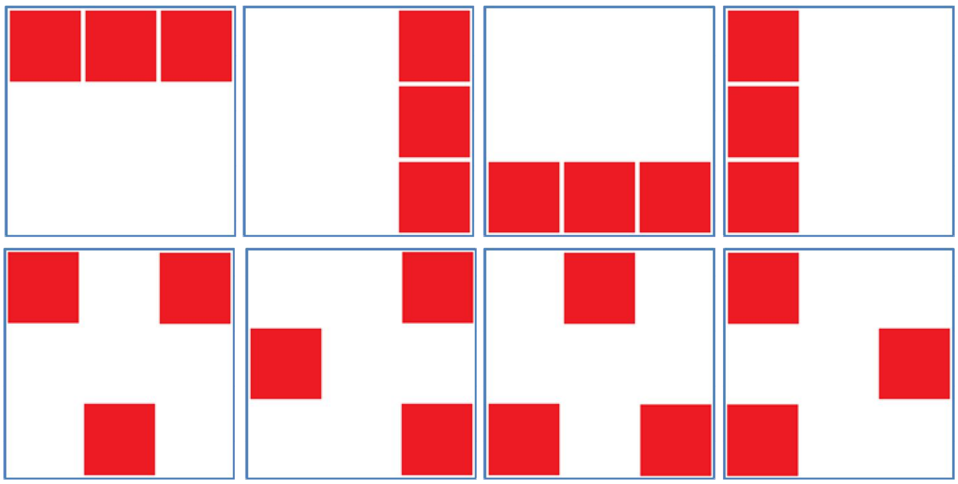


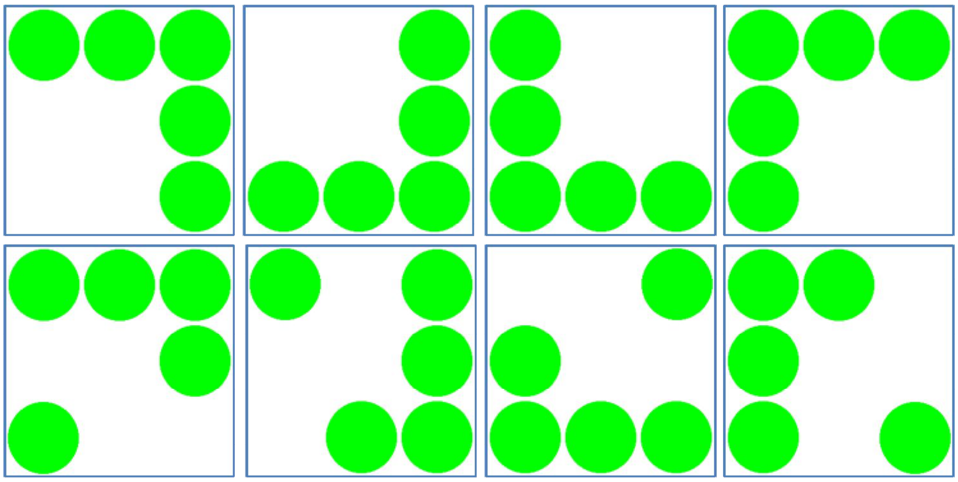


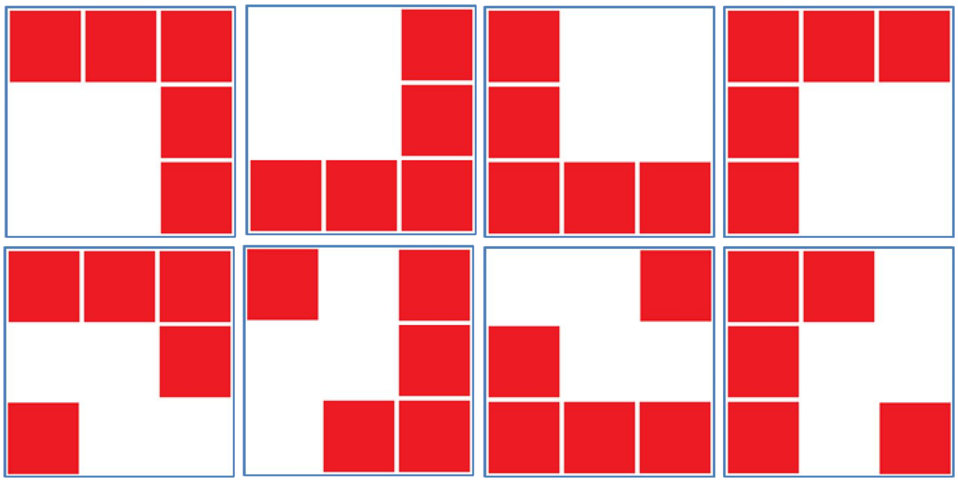




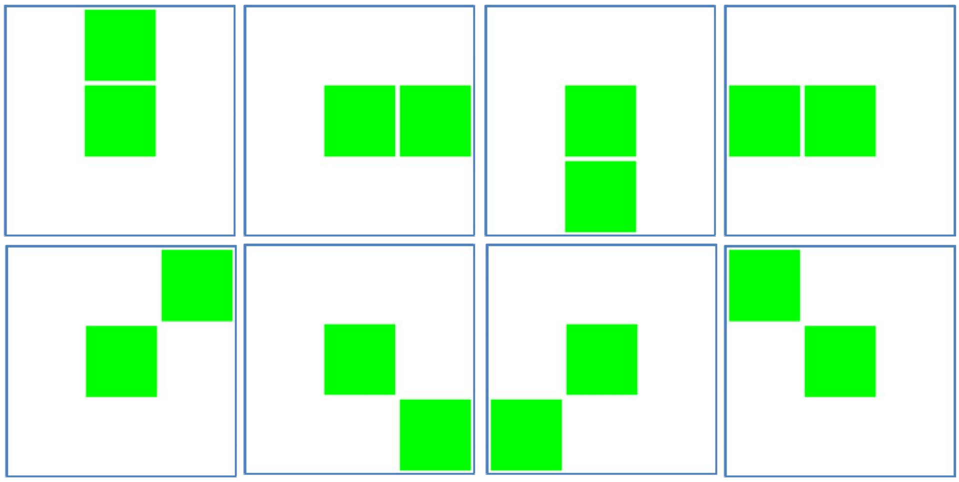


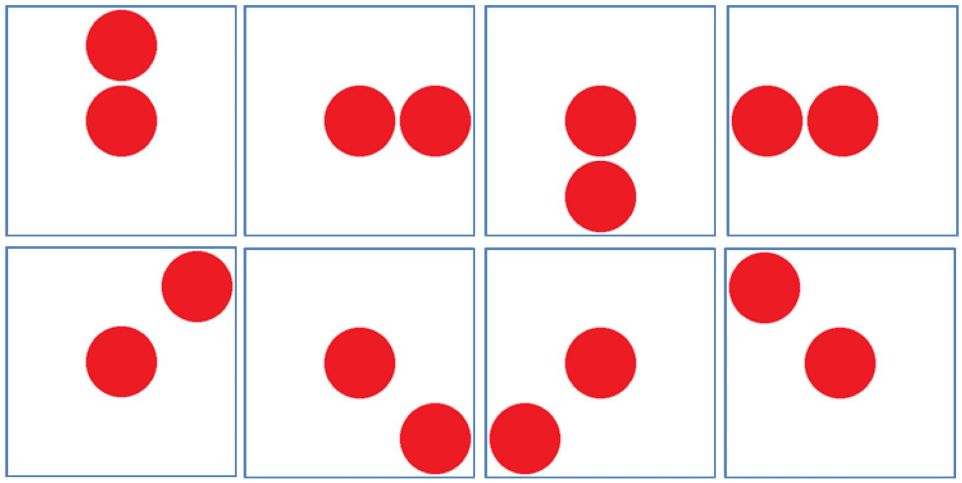


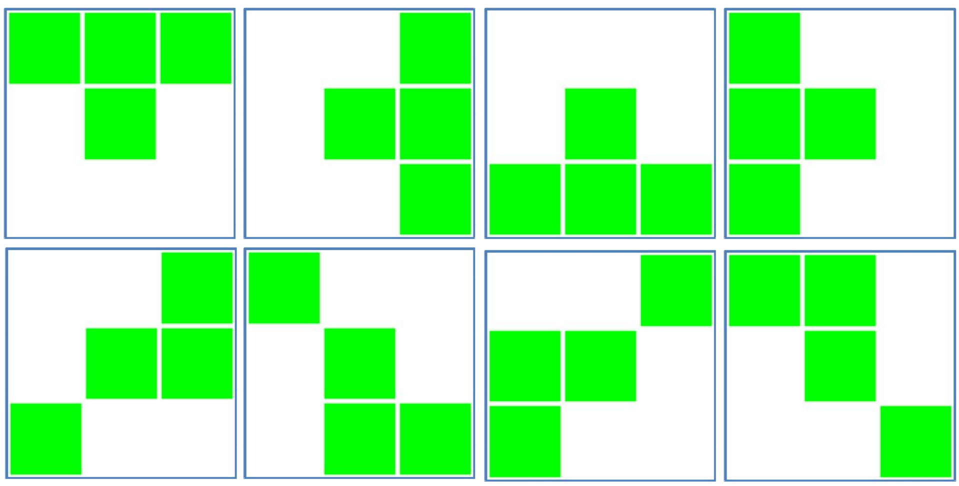


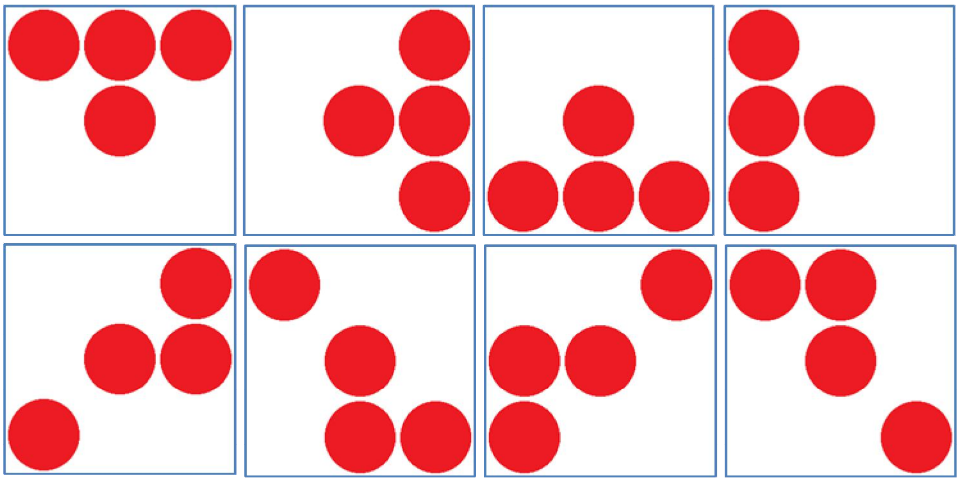


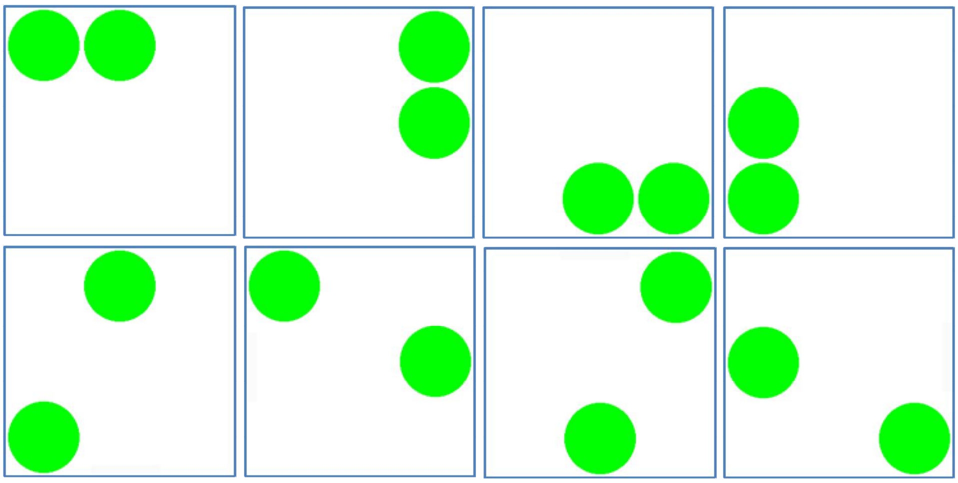
Distractor Templates: Grouped by row, rotated through 360°

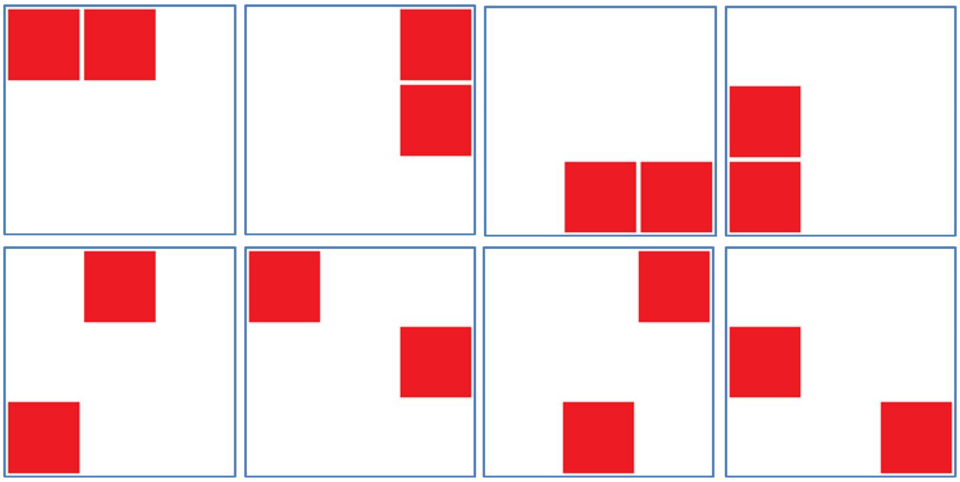


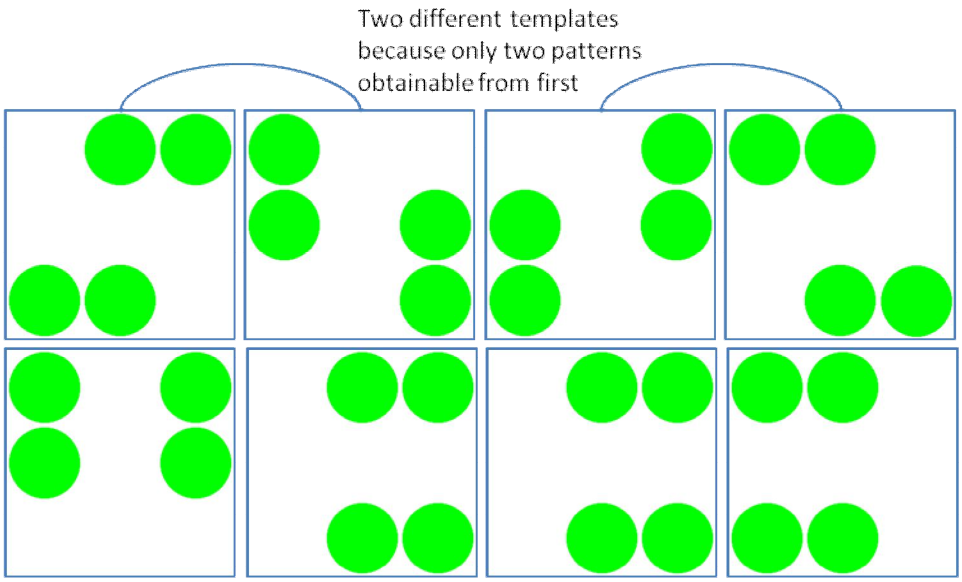


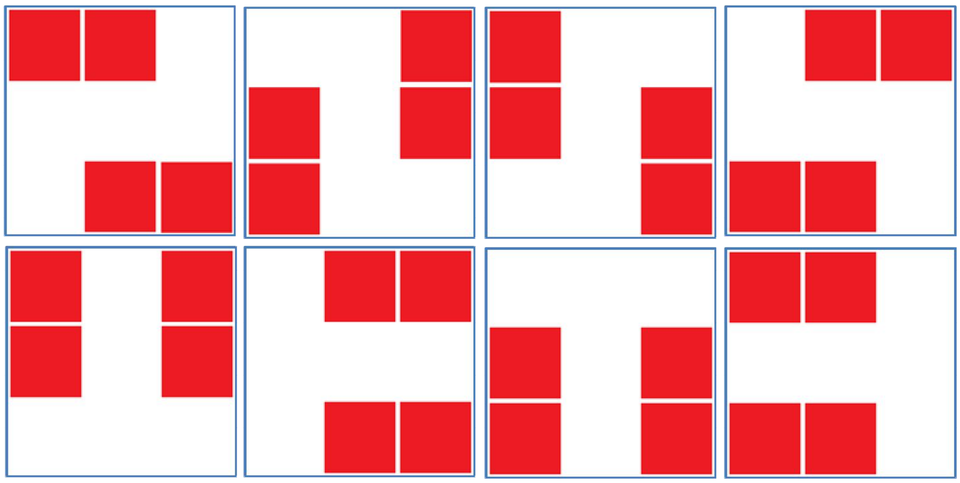









Two different templates
because only two patterns
obtainable from first



8.2. Distractor Stimuli - Experiments 5 – 7