An Investigation of Sensory Integration across the Autistic Spectrum using Multisensory Illusions.

Salik Masood

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This one is for you mum and dad. This would have not been possible without your constant support, love and Patience. Thank you for believing in me and giving me the freedom to pave my own path. I love you786

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Abstract

In order to have a comprehensible representation of scenes and events, the human brain must combine information from different sensory sources. Integration of visual, tactile and proprioceptive information is considered vital to this process as it underpins the subjective sense of self and body ownership; which has been linked to the development of social processes such as empathy and imitation. This issue has been investigated using sensory illusions and suggests that individuals with autism are less prone to multimodal illusions due to atypical sensory integration, i.e. they tend to rely on a single sensory source more, rather than integrating concurrent sources of information (i.e. over- reliance on proprioception). Studies that have measured illusion susceptibility and ownership, especially in regards to body ownership have provided mixed results. Therefore, it is important to understand and advance our knowledge on illusion susceptibility using sensory illusions.

In order to conduct this research it was first required to identify typically developing individuals who have high and low autism tendencies using the Autistic Spectrum Quotient (Baron-Cohen et al., 2001b). This was important because previous research has indicated behavioral similarities between individuals with high autism traits and those with high- functioning autism (HfA). The primary aim of this research was to investigate whether individuals with high autism traits and those with a diagnosis of autism perform in a similar way in terms of illusion susceptibility and illusion ownership, as previous research has stated differences in illusion susceptibility (Palmer et al., 2013; Paton et al., 2012).

Three different multisensory illusions were presented to all the participants using the MIRAGE mediated reality device. This device enables the experimenter to present

various illusions on the participants' limbs, where manipulations can be applied over the hand. Illusion ownership and susceptibility statements were used to measure the subjective experience of the participants, whereas, finger localization tasks were used as an objective measure of susceptibility to the illusions.

Experiment One and Two investigated the effects of crawling skin illusion which is a visual illusion that can produce somatosensory sensations without any tactile input- as this illusory percept manipulates an individual's existing knowledge regarding their own hand (McKenzie & Newport, 2015). The results indicated that individuals with high AQ scores (compared to low AQ, Experiment 1) and HfA (compared to typically developing adults, Experiment 2) showed less influence of visual context. They reported reduced effects of the illusion, which could be due to a higher reliance on top- down knowledge. However, all the participating groups showed high ownership of their hand as viewed through the MIRAGE.

Participants with high and low autism traits (Experiment 3) and adults with HfA as well as typically developing adults (Experiment 4) were presented with the finger stretching illusion (Newport et al., 2015) which involves an interplay of vision, touch and proprioception. The results obtained showed that participants across all groups had high ownership score, however, only the low AQ group and the control group were susceptible to the illusion. An estimation task was used to measure whether participants embodied the illusion, adults with high AQ scores and HfA showed superior performance during the estimation task, however, the control groups estimates were significantly further, hence, making them more susceptible to the visuo- tactile manipulation.

The third illusion measured visuo- proprioceptive integration in individuals with high and low AQ scores (Experiment 5) and adults with HfA as well as typically developing adults (Experiment 6). The task involved participants estimating the location of their hidden index finger under different conditions i.e. participants were able to view their hand or the view of their hand was hidden. Participants first took part in an adaptation procedure (Newport & Gilpin, 2011) which involved relocating the hand from where the participants last saw their hand. This was to test whether individuals with high autism traits and those with HfA showed superior proprioceptive performance in estimating their index finger location. The results indicated that the HfA and the high AQ groups were less affected by the visuo- proprioceptive misalignment caused during the adaptation procedure. Participants with low AQ scores and the typically developing group's estimates were more influenced by the visual input.

In conclusion, none of the experiments found strong evidence of over-reliance on proprioception in individuals with high AQ or those with HfA, however, they showed superior estimation abilities than the control group. My findings suggest that there is a preference, but not over- reliance on, for proprioception as opposed to visual and tactile information in the high AQ scoring group and the HfA group. Over- relying on a single sensory source, while not integrating multisensory information could have a detrimental impact on sensory processing and social interactions, especially the visuo- tactile system as it enables an individual to experience the environment through touch and understand everyday sensations such as temperature, pressure, itching, pain, etc. For future research, this research highlights the importance of studying the visual tactile domain. An individual's ability to process tactile input is related to their ability to visually discriminate and to have appropriate body awareness, which in turn helps in developing emotional security, academic learning and social skills that are some of the core issues often reported in individuals with autism (Corbett et al., 2009; Happé & Frith, 2006; Piek

& Dyck, 2004; Tager-Flusberg, 2008). More so, research investigating such processes should involve the whole spectrum of autism rather than focusing on a smaller subset.

General Introduction

Chapter One

1.1. Overview

When we interact with the world around us, it involves integrating information from various sense modalities which include sight, sound, taste, touch and smell. For example, research has demonstrated that up to seventy percent of the taste of food is influenced by the sense of smell (Atteveldt et al., 2014). Another such example would include threading a needle which involves extremely close communication between visual and proprioceptive[1] and motor output to succeed; where online feedback constantly updates hand position according to visual feedback. Furthermore, because majority of an individual's sensory input is achieved through motor and attentional sampling routines, perception can also be considered as a sensorimotor process (Schroeder et al., 2010). For an individual to understand as well as interact with the external world, the brain must integrate information from multiple sensory modalities to establish a unified representation of the world around. The successful integration of these individual sensory inputs is considered as an essential part of interaction and perception. For example, vision and touch help to estimate the shapes of objects, whereas, vision and auditory information are important in speech comprehension

[1] Proprioception is defined as the sense through which we perceive the position of our body in relation to the surrounding environment and moderate's movement (Jones, 2000).

(Schroeder et al., 2010). Multisensory integration also aids in the development of social interactions, as it helps in picking up cues from peoples' body language and facial expressions. Therefore, multisensory integration has been investigated in relation to social interaction and body ownership.

Autism spectrum disorder (ASD) is a developmental disorder which is characterized by deficits in social communication and interaction across multiple contexts and restricted, repetitive patterns of behaviors, interests and activities which include hypo- or – hyperactivity to sensory input or unusual interests in sensory aspects of the environment (American Psychiatric Association, 2013a). A growing body of evidence suggests that the core deficits often associated with the disorder is due to atypical multisensory integration (De Gelder & Bertelson, 2003; Russo et al., 2010; Marco et al., 2012), with sensory deficits today being a core criterion in the diagnosis of autism in the Diagnostic and Statistical Manual of Mental Health Disorders (Edition 5) (DSM- 5). Some very common reactions of sensory stimuli in autism include avoidance of light touch to the head and body which occur while grooming and cloths with certain textures. Another very commonly seen sensory behavior includes avoidance of visual stimuli (e.g. covering eyes at bright lights) or they seek additional visual stimuli (e.g. twisting fingers in front of eyes) (Marco et al., 2011). The earliest of theories of autism are established on the premise that individuals with autism process sensory information in a different way compared to typically developing individuals (Frith, 1989; Happé, 1999)

It has already been established that integration of multiple sources of sensory information aids us in understanding our surrounding environment, helps us to make sense of our surroundings and also aids in interacting with it. More importantly, integration of visual, tactile and proprioceptive information helps in the development of sense of body ownership (Tsakiris, 2011). It helps in establishing a sense of bodily self and body localization and also helps in understanding that our body belongs to us and we can control it ourselves (Gallagher, 2000). Body ownership is the knowledge that your body belongs to you, and is constantly there, and it serves as the basis of self- awareness and can help people to understand their own emotions and sensations. Furthermore, the ability to understand another individuals perceptions, emotions and intentions are only possible by comparison with our own actions and intentions from the past and the present (Meltzoff, 2007), therefore, body ownership can also be considered necessary for higher- order cognitions (Gallese et al., 2004; Chaminade et al., 2005; Gallese, 2006). Furthermore, these processes are also considered crucial for the formation of personal psychological identity (Cassam, 1997; Seth & Edelman, 2004).

Body ownership is also important in terms of social cognition as it serves as the foundation for the development of empathy and imitation. Meltzoff and Moore (1997) suggests that it helps in recognizing similarities between our movements and those of other individuals. Body ownership also helps enables an individual to infer others' mental states and this has been demonstrated in studies with infants during which infants learnt to grasp an object that they desire demonstrating the understanding of the relationship between one's own desire and reaching for it (Repacholi et al., 2008). Furthermore, many researchers have also argued that the ability to understand and detect similarities and differences between our own and others movements is critical for developing empathy and for understanding things from another person's point of view (For e.g., Smith et al., 2010; Bosse et al., 2015).

Previous research focusing on multisensory integration in individuals with ASD have used different experimental paradigms to test sensory integration. Vision and auditory sensory information has been studied far more than visual, tactile and proprioceptive information (Foss-Feig et al., 2010; Paton et al., 2012; Greenfield et al., 2015) . Visual and auditory integration can serve as the basis of verbal communication and speech perception. Visual, tactile and proprioceptive integration are integral for the development of self and body ownership (Makin et al., 2008), and these processes are considered as a precursor for the development of empathy, self- awareness and imitation (Schütz-Bosbach et al., 2006). Furthermore, these processes are impaired in ASD and are essential social processes, therefore, understanding the integration of these sensory inputs is crucial. Recent research suggests that those with a clinical diagnosis of autism and those of typical development but with high number of autism traits (Baron-Cohen et al., 2001b; Ruzich et al., 2015a), often display similar behavioral characteristics to those with a diagnosis.

Experimental studies have investigated visuo- tactile and proprioceptive integration in typically developed adults as well as people with ASD using multisensory illusions in order to understand the mechanisms of multisensory integration and the dependence on top- down and bottom- up processes. In the following sections, a detailed account of Autism spectrum disorders and the sensory issues often reported in ASD will be reported. The overall aim of this thesis is to measure illusion susceptibility towards multimodal illusions that represent an interplay between vision, tactile and proprioceptive inputs. I will cover how sensory processing can be atypical in unimodal processing, focusing on tactile and visual processing as well as the traditional theories of autism that have been used to explain atypical unimodal processing and the more recent theories that have tried to explain atypical visual- tactile integration in autism.

1.2. Autism Spectrum Disorders

Autism was first discovered when Kanner (1943) first noted the following statement made by the mother of a child with autism "When books are rearranged on the bookshelf, he always rearranges them in a certain order". This sort of behavior was found consistently in many anecdotal and clinical reports of individuals with autism where they tend to focus on features about situations and events that other might find insignificant. Autism is diagnosed when a child or adult has abnormalities in a “triad” of behavioral domains: social development, communication, and repetitive behaviors. However, over recent years, rise in the prevalence of sensory related abnormalities has now included sensory disturbances as a core characteristic of an autistic disorder. Autism is not an isolated disorder as it runs on a spectrum (See Figure 1.1), not only on a human level but also on a traits/ behavioral deficits continuum. Autism can occur at any point over the IQ continuum, and IQ is a strong predictor of the outcome. Autism is also accompanied by a language delay. Asperger’s syndrome, now known as high- functioning autism is a sub-group on the autistic spectrum. Individuals with HfA share many of the same features as are seen in autism, but with no history of language delay and with an IQ in the average range or above- in reference to the normally developing individual (Adolphs, 2003; S. Baron-Cohen, 2004; McClelland & Ralph, 2015)

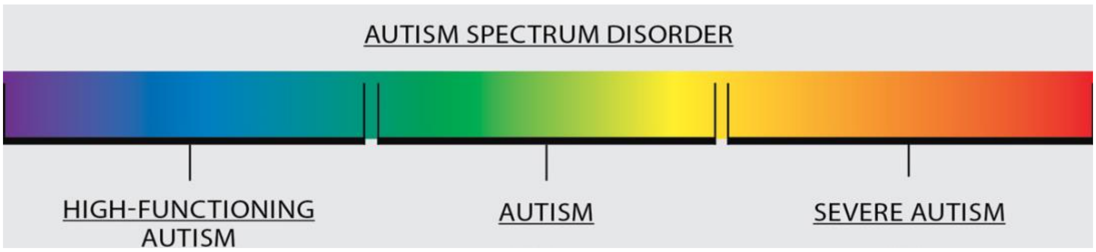


Figure 1.1. Graphically explains the spectrum of Autism Spectrum Disorders. According to DSM-V, the spectrum is divided into three levels i.e. Level 1 high- functioning autism, Levels 2 Autism and level 3 severe Autism. High- functioning autism is when an individual has an IQ score of that of a TD individual of similar age and gender. Level 2- Autism is characterized by the need of substantial support. Communication skills, social skills and repetitive behaviors are very obvious to a casual observer. Level 3- Severe Autism is characterized by severe impairment in social and non- social skills, repetitive behaviors and verbal and non- verbal communication behaviors that impair the patients daily functioning.

The Centers of Disease Control (2013) estimates one in every 88 children in the world is diagnosed with autism spectrum disorder (ASD). ASD is a genetic disorder whose etiology is as of yet still unclear; however, the prevalence of this condition is on a rise and a total of .3 to .6% of the world's population has a clinical diagnosis of ASD. In comparisons to other developmental conditions, such as dyslexia or attention deficit disorders, ASD is one of the most prevalent clinical conditions across the life span (Centers for Disease Control and Prevention, 2012). Currently, ASD is diagnosed by assessing behavioral deficits that present themselves in an individual which include: social and communicative deficits, such as lack of social reciprocity and shared enjoyment, non- verbal communication deficits, stereotyped speech and a delayed language acquisition) as well as the presence of restricted or repetitive behaviors and interests (American Psychiatric Association, 2013a). Signs of autism can often be detected at 18 months of age or even younger. By the age of two, a diagnosis from an experienced professional can be considered very reliable. However, many children do not receive a final diagnosis until much older. Unfortunately, some individuals are not diagnosed until they are adolescents or even adults (CDC, 2020)

Initially, ASD was defined by the core behavioral deficits, however, it is now seen from a integrative point of view and this is largely due to the capacity of these components to produce effective social interaction (Frith & Happé, 1994a; Ropar & Mitchell, 2001; Uljarevic, Prior, & Leekam, 2014). The prevalence of sensory issues in ASD has been reported by 80 to 90% of individuals with a clinical diagnosis of autism, ranging from a single sense modality and spreading across several senses. A study by Leekman et al (2007) used parental reports to establish the prevalence of sensory abnormalities in the diagnosed children and the results of the analysis reported that 90% of the children studied exhibited some type of sensory abnormalities (Leekam et al., 2007). Caminha and Lampreia (2012) highlighted studies that found that between 70 to 80% of individuals with ASD had sensory abnormalities i.e. hypo-and/ or hyper responsiveness to sensory stimuli, where individuals with autism are distressed when there is a sensory overload in unfamiliar settings. Furthermore, Donohue et al., (2012) have reported that more than 90% of the sample in their study reported some sort of sensory issue, whereas, within that population 80% of children and adults reported having sensory issues in more than one sense modality. Tomchek et al., (2014) also suggested that reactions to sensory stimuli are often displayed in two different forms in ASD, such as individuals with autism often exhibit an aversion to certain sensory stimuli (e.g., withdrawing from noises like a baby crying or the loud sound of a lawnmower) or alternatively, seek out sensory experiences through stimulatory behaviors (e.g., peering, echoing, tapping surfaces or twirling fingers in front of their eyes). These behaviors are often labeled as hypo or hyper-responsiveness to sensory stimuli in the popular literature (Lovaas et al., 1987; Kern et al., 2006, 2007). Therefore, with the increase in the reports of sensory problems in autism, sensory abnormalities have become a core diagnostic criterion in order to attain a clinical diagnosis of autism.

1.3. Multisensory Integration

Multisensory Integration (MSI), also commonly known as multimodal integration, is defined as the process of how information from different sense modalities, such as sound, sight, touch, smell, self- motion and taste, are integrated by the central nervous system. The biggest advantage of MSI is that these processes allow humans to route information more effectively and aid in how they respond to external stimuli (Calvert et al., 2000; Foxe & Molholm, 2009; Hillock et al., 2011; Lewkowicz, 2010; Powers et al., 2009; Powers et al., 2016). It has also been suggested that MSI facilitates reactions times which leads to faster responding, which eliminates the effects of redundancy (Calvert & Thesen, 2004). Furthermore, MSI is considered as a critical process and forms the basis of perceptual experiences such as performing behaviors, understanding others intentions and actions and also the perception of objects and events in the external world (Calvert & Thesen, 2004; Shi & Müller, 2013). Previous research has not only highlighted the importance of these processes but has also demonstrated how MSI can aid in many perceptual processes. For example, we often immediately turn our heads if someone calls our name in a crowded area, indicating that both vision and auditory sensory information accelerates detection. Many studies have highlighted the importance of MSI and how it shapes perceptual processes (Driver & Spence, 1998; Calvert & Thesen, 2004; Spence, 2010; Spence & Driver, 2012; Shi & Müller, 2013) For example, Calvert & Thesen (2004) suggested that interaction of the senses is vital to maximize how efficiently and effectively individuals interact with the environment. Therefore, for an individual to benefit from the simultaneous stimulation of multiple sensory sources, such as visual, tactile and auditory information, is the core of successful perceptual experiences i.e. human interaction.

Multisensory integration has been studied widely in individuals with typical development and those with developmental and neurological issues such as schizophrenia (Stekelenburg et al., 2013), individuals suffering from medically unexplained symptoms (Funahashi, 2007), autism spectrum disorders (Vroomen, & van der Heide, 1991; Cascio et al., 2012; Paton et al., 2012; Palmer et al., 2013; Stevenson et al., 2014; Greenfield et al., 2015) and individuals with sensory processing disorder (Mottron et al., 2006; Russo et al., 2010) and many more. MSI plays a very important role in perception, therefore, in order to under the underlying processes that contribute to successful integration of multiple sensory inputs has been studied abundantly in the typically developing population using various different experimental paradigms.

Multisensory integration can often be seen in a majority of perceptual illusions, where the presentation of a signal in one sensory modality can modulate perception in another. The reason to use multisensory illusions as a tool to understand MSI is to comprehend how the brain is receiving multiple sources of information, such a sight, taste, hearing, touch and smell, but somehow it manages to filter out unnecessary information and links the current information to contextual knowledge and makes logical sense of its environment. One of the most compelling illusions is the sound induced flash beep illusion, in which the participant is presented with a single visual flash paired with multiple auditory beeps in a succession. The participants are instructed to ignore the audio stimuli and focus only on the visual stimuli. The results of the illusion are such that the audio stimuli facilitates the presence of the visual stimuli, such that when two beeps are presented, people often report two flashes even though there is only one. This indicates alteration of the visual percept due to the cross- modal interactions as opposed to cognitive, attention or other factors (Shams et al., 2000).

Another extremely compelling and common method for examining audiovisual speech perception is the famous "McGurk Illusion". In this classic paradigm, individuals are presented with incongruent visual and auditory stimuli. Individuals often report that they hear an illusory fused sound (for e.g., a video of a person articulating 'ga-ga' dubbed on the sound of 'ba-ba'- and the individuals report hearing 'da-da') that is different from both the auditory and visual inputs (McGurk & MacDonald, 1976) or the participants report hearing the visually presented phoneme pair reflecting the influence of visual inputs on auditory speech perception (Boston, 1977). McGurk illusion is considered as a robust and reliable illusory paradigm and a powerful tool of assessing the integrity of audiovisual speech perception. It highlights the influence of visual input on auditory speech perception. Similarly, several studies have used these paradigms and investigated visual and auditory perception in the typically developing population by assessing the susceptibility of children and adults towards these experimental paradigms. However, studies that have used these paradigms with children and adults with autism, have provided evidence indicating that individuals with autism do not fall for this illusory precept, this suggests that autistic individuals tend to over-rely on the details while not comprehending the central idea.

1.4.Sensory Processing In Autism Spectrum Disorders

Individuals with ASD do not combine multiple sources of sensory information in order to come to a conclusion (Kern et al., 2007; Smith & Bennetto, 2007; Marco et al., 2012; Matsushima & Kato, 2013). This could be due to an over- reliance on a single sensory input at a time while ignoring the rest. This could make it difficult for these individuals to combine information in an optimal manner leading to atypical behaviors. Sensory processing deficits in ASD are present in both simple sensory input and unimodal sensory input to more complex processes that involve the integration of multiple sensory inputs. Therefore, in the current thesis I will be measuring the susceptibility of individuals with HfA and those of typical development to illusions that require the integration of multiple sensory sources. ASD can affect sensory integration, especially situations where sensory information is integrated in an atypical manner in people with ASD, within and across modalities (i.e., audition and vision).

There are rarely any situations during which we are not confronted with sensory information from more than one modality (i.e., sight, sound, smell, touch) at any one time but we are always experiencing more than just a single sensory source (De Gelder & Bertelson, 2003). For example, if we take a stroll outside, our brains are making sense of several different pieces of sensory inputs: the sights and sounds around us, the smells lingering in the air or listening to a friend is a relatively crowded environment and watching their lips move to make sense of what they are saying. Therefore, we must constantly combine these pieces of information together to make sense of the actions happening around us, interpret it in time and then behave accordingly in response to it. However, individuals with autism would tend to avoid such situations as it would put them under sensory overload, i.e. reactions to children crying or screaming is very common (Whyatt & Craig, 2013; Fazlioğlu & Baran, 2008).

1.4.1. Visual and Tactile Sensory Processing in ASD

Individuals with ASD exhibit atypical visual behaviors that can be categorized into, they either attempt to avoid certain visual input by covering their eyes at bright lights or they seek additional visual stimuli by twisting their eyes in front of bright lights. Studies investigating visual processing in ASD have provided with mixed results, there are reports suggesting enhanced detail perception for simple stimuli, but impairment in more complex tasks (Bertone et al., 2005). Threshold studies using contrast sensitivity and motion perception to test visual perception have found no differences in those with autism and typically developing counterparts (Koh et al., 2010), other studies have shown that individuals with autism have impairments in object boundary detection (Vandenbroucke et al., 2008) and contrast detection (Sanchez-Marin & Padilla-Medina, 2008). Similar to many other studies reported, the findings suggest that the ability to integrate incoming visual information becomes increasingly challenging when the task becomes more demanding (Shams et al., 2000; Walter et al., 2009; Marco et al., 2012; Salowitz et al., 2013)

Within the visual domain, one of the most extensively studied areas in autism is that of face processing as it is considered a crucial skill for human social interaction (Gelder et al., 1991; Schültz et al, 2006; Kanwisher & Yovel, 2006; Irwin et al., 2011). Faces offer a wealth of cues important for social interaction by conveying important information such as identity, emotional expression and gaze direction (Nomi & Uddin, 2015). Some of the most pronounced social deficits characteristic of autism are diminished interest in and attention to the human face where individuals with autism struggle to recognize facial emotions and facial cues (Webb, Neuhaus et al., 2017; Webb, Jane et al., 2016; Weigelt, Koldewyn et al., 2011;Weigelt et al., 2012). Similar to other areas of sensory processing, face processing abilities have been widely studied in people with ASD, where researches have used both implicit (Grice et al., 2001) and explicit methods (e.g. behavioral tasks) (Marco et al., 2011), where the results generated have been inconsistent. Even though implicit measures of face processing in ASD have provided us with fairly consistent results, such as deficits in identification of faces and facial cues (Weigelt et al., 2012) and facial expression processing (Uljarevic & Hamilton, 2012), a lot of variability exists in the outcomes of studies that have used behavioral measures. These differences, such as increased reaction times and reduced accuracy, have been attributed to the various confounding variables that influence's task performance beyond facial recognition such as attention and motivation (Wallace et al., 2006; Webb et al., 2017). Research has indicated that processing facial stimuli is not only influenced by the emotional valence of the stimuli, but attention and motivation can have significant effects on the participants judgements (Oliveira et al., 2013; Calder et al., 2015; Chevallier et al., 2015), tasks that are more time-consuming can alter judgements. Furthermore, tasks involving multiple testing phases can impact the outcome of the next test block in individuals with autism. In terms of motivation, tasks that are time- consuming can be very demanding for individuals with autism and many of them suffer from attentional deficits of genetic causes and some have a dual diagnosis of autism and an attention deficit disorder (Hill, 2004; Marco et al., 2011; Leitner, 2014) .Even though attentional and motivational deficits have been attributed to face processing tasks, these factors can also impact judgement in other tasks.

Tactile atypicalities are also commonly reported in ASD, which is commonly manifested in the form of tactile sensitivity where unlike neurotypicals individuals with autism can react negatively to certain textures i.e. silk versus cotton. Even though this is commonly reported by individuals with a clinical diagnosis of autism, this area has received far less attention in the neuroscience literature than the auditory and visual counterparts (Wiggins et al., 2009). The most commonly reported complaint is the avoidance of light touch to the head and body while grooming and the contact with certain textures or clothing. These have been reported as possible reasons to cause significant amounts of anxiety in those with ASD. Coskun and colleagues (2009) recently investigated somatosensory mapping in high- functioning adults with and without autism using magnetoencephalography (MEG) and found that adults with high functioning autism appear to have disrupted cortical representations of their face and hands (Coskun et al., 2009). Several psychophysical tactile studies have used vibrotactile stimuli to look at the thresholds and sensitivities of adults with and without autism and Asperger's. One such study showed significantly lower tactile perceptual thresholds in individuals with Asperger's syndrome or high functioning autism (Blakemore et al., 2006), and others have shown tactile hypersensitivity to vibrotactile and thermal stimuli but not to light touch in adults with autism (Cascio et al., 2008). In contrast to these studies, a study with a small sample of children with autism showed no differences in tactile thresholds for vibrotactile stimuli detection between children with autism and neurotypicals (Güçlü et al., 2007). To my knowledge, there is a limited number of studies that have focused on tactile sensitivity in autism. This shows that there is a scarcity of studies in this sensory domain, however, it also highlights the need for further exploration in this area as touch is a proximal sense that appears with particularly high frequency in autism and also severs as a basis of early attachments and social interactions (Weiss et al., 2000). Another aspect related to sensory difficulties is sensorimotor deficits seen in autism. Therefore, now I will be discussing how sensorimotor difficulties contribute towards the atypical social and non- social deficits reported in autism.

The weak central coherence theory and the enhanced perceptual functioning theory are largely cognitive driven which can be argued as being functionalist and fragmented (De Jaegher, 2013a, 2013b), such that they do not include or explain for the diverse range of symptoms associated with ASD. The strong cognitive thread present amongst both these theories mostly reflect the cognitive and social symptoms of ASD, however, these complex levels of cognition do not even emerge until the child turns three years old (Whyatt & Craig, 2013), whereas, sensory motor difficulties are apparent within the first years of an infant's life (Osterling & Dawson, 1994; Mattila et al., 2007; Dawson et al., 2012). Mounting amounts of evidence indicates the presence of significant sensory- motor difficulties across the entire autism spectrum and more so even in those who display some traits of autism but not enough to warrant a clinical diagnosis (Dawson & Watling, 2000; Baranek, 2002; Fournier et al., 2010; Whyatt & Craig, 2013). Some commonly reported sensory- motor problems often reported in autism include issues with balance, problems in coordination and praxis (Kopp et al., 2010; Whyatt & Craig, 2012; Zwicker et al., 2012; Gowen & Hamilton, 2013). Furthermore, studies have reported deficits in motor skills, such as hypotonia (low muscle tone) and apraxia (difficulty to execute a planned physical movement) (Ming et al., 2007; Wigham et al., 2015; Hannant et al., 2016). Even more, studies have also reported slower repetitive hand and foot movements, slower and inaccurate manual dexterity, poorer ball throwing skills and reduced coordination of locomotor skills, such as jumping and running (Piek & Dyck, 2004; Green et al., 2009; Haswell et al., 2009; Hannant et al., 2016). Fournier et al., (2010) conducted a meta-analysis with 51 comparisons of motor ability and found that participants with ASD displayed a pronounced motor and sensory impairments compared to typically developing counterparts, with almost 98 percent of the autism sample reporting two or more sensory- motor issues (Fournier et al., 2010). Sensory- motor problems in autism do not only exist at a physical level but recent research indicates deficits at a neural level, whereby, individuals with autism show weak links between sensory and motor brain networks and the strength of these links has been corelated with the severity of autism traits (Oldehinkel et al., 2018).

Studies examining human motion in the autism population have also documented several prominent difficulties with movement initiation, preparation of such thought movements and also implementation of actions (Schneiberg et al., 2002; Mari et al., 2003; Hochberg et al., 2012; Papadopoulos et al., 2012; Whyatt & Craig, 2012). These motor problems appear to reside as a fundamental problem with the temporal control of movement, with both akinesia and hyper-dexterity also being frequently documented (Whyatt & Craig, 2012; Whyatt & Craig, 2013). Furthermore, Price et al, (2012) found out that differences in movement timing has a high significant correlation with poor motor coordination, implying that spatial movement difficulties in autism, such as problems with starting a movement or stopping a movement or action- controlling movements and a tendency to lose the rhythm of a movement are all due to some form of delayed temporal cause (Donnellan et al., 2012; Price et al., 2012; Robledo et al., 2012). The studies reviewed so far, alongside, the sensory issues reported in autism indicate that sensory and motor problems are present in autism and they have a detrimental effect on social functioning (Macdonald et al., 2013; Matsushima & Kato, 2013), and also studies indicate that these deficits are present from birth, i.e., pre- social skills deficit (Brisson et al., 2012; Landa et al., 2016) and can be a huge indicator that the child might develop autism by he/ she turns three years of age (Landa & Garrett-Mayer, 2006; Geschwind & Levitt, 2007). Therefore, all this indicates that there is an impairment in the processing of sensorimotor integration, i.e. the connection of the motor and sensory domains, that plays a crucial role in the development of various social deficits reported in autism spectrum disorders. In addition, Siaperas et al., (2012) demonstrated that children with autism showed significant impairment's in motor performance and proprioceptive and vestibular processing and, therefore, suggested that sensory difficulties are not a minor but definitely a core feature of autism (Mockett, 1993; Siaperas et al., 2012).

There is a strong relationship between sensory feedback and movement, as the ability to plan and execute a simple movement, such as reaching for a toothbrush, requires sensory feedback, i.e. where your body is in relation to the environment and the object, in order to successfully coordinate the movement while performing the action (Gowen & Hamilton, 2013). As these movements are continuously repeated in daily life, they become automatic and the delay caused by the sensory feedback is reduced with each movement, as the motor command automatically generates a prediction of the sensory consequence of the action (Todorov & Jordan, 2002; Diedrichsen et al., 2010). Therefore, when these sensory signals become unreliable, slow or altered, both the motor common and the action associated with the motor command become impaired which leads to limited flexibility and an inaccuracy in performing that particular action. Hence, deficiencies in sensorimotor integration would present as difficulties in properly utilizing sensory feedback to correct movements, which would lead to coordination difficulties and sensory reactivity abnormalities such as those seen in autism (Rogers et al., 2003; Fabbri-Destro et al., 2009; Brisson et al., 2012; Cossu et al., 2012). A number of studies have reported sensorimotor integration difficulties in autism (Glazebrook et al., 2007; Glazebrook et al., 2009; Price et al., 2012; Ronconi et al., 2013). Ronconi et al., (2013) showed that visual attention was impaired in children due to an imbalance of feedforward and feedback sensorimotor programs. Price et al., (2012) demonstrated that children and adults with autism showed compromised visual sensitivity towards human motion, whereas, Glazebrook et al., (2009) showed that adults with autism took significantly longer times coordinating both eyes and hand movements compared to typical controls. Studies have also shown that individuals with autism show a difficulty in integrating sensory information in motor learning. Dowd et al., (2012) demonstrated that when children with autism performed a motor learning task on a touch screen with a visual distractor, the distractor did not hinder their performance compared to neurotypicals (Dowd et al., 2012). Several studies have also highlighted that children with autism are significantly less able to correct movements from visual compared to proprioceptive feedback (Gepner & Mestre, 2002; Schmitz et al., 2003; Gepner, 2004; Ming et al., 2007) . Furthermore, studies have also demonstrated specific difficulties with motor movements, which require integrating visual cues or other sensory signals in autism (Gowen & Miall, 2005; Price et al., 2012; Gowen, 2012; Whyatt & Craig, 2012; Gowen & Hamilton, 2013). Additionally, children with autism also have difficulty when tracing shapes using feedback from a mirror image and also when imitating others actions (Meltzoff & Gopnik, 1993; Charman et al., 1997; Salowitz et al., 2013). The findings from all the research mentioned above indicates that children and adults with autism have a difficulty incorporating sensory inputs, particularly visual inputs, into motor learning and show difficulty coordinating visual and motor movements. Therefore, these difficulties could particularly impact social learning which is learnt through imitation and integration of eye movements with gestures during social communication, thus, resulting in social and non- social deficits often reported in autism spectrum disorders (Piek & Dyck, 2004; Happé & Frith, 2006; Tager-Flusberg, 2008; Iarocci et al., 2010; Cossu et al., 2012).

1.5. Cognitive Theories of Sensory Processing in Autism

There are four dominant cognitive theories that attempt to explain the core features of autism in terms of underlying cognitive deficits; these include theory of Mind (ToM) (Baron-Cohen et al., 1985; Baron-Cohen, 1989), Weak Central Coherence Theory (Frith, 1989), Enhanced Perceptual Processing Hypothesis (Mottron et al., 2006) and Executive Dysfunction theory (Elliott, 2003). All these theories have importance in explaining autistic behaviors; however, I will focus only on the Weak Central Coherence theory and the Enhanced Perceptual Processing hypothesis as these two theories are the most relevant to the aim of the current investigation.

1.5.1. Weak Central Coherence Theory

The weak central coherence theory (WCC) (Frith, 1989; Frith & Happé, 1994; Happé, 1999) tries to explain some of the social and non- social deficits in autism, that are considered both as "deficits" and "savant" skills, such as the extreme attention to detail that is often considered as obsession, but under certain conditions this behavior flourishes. For example, individuals of typical development process information by focusing on the entirety of an object or situation by extracting the overall meaning or gist, which is often termed as "Global processing". Frith and Happé (1994a) suggested that the act of driving the overall meaning was absent or weak in autism and instead individuals with autism process things in a detail- focused way by processing the constituent parts, rather than the global whole. Global information processing, which is the ability to integrate piecemeal information into a coherent whole i.e. to grasp the gist- is critical in sensory processing, communication and social interaction (Navon & Norman, 1983; Happé & Frith 2006). I will be using this definition of "global processing" throughout this thesis especially when discussing differences between local and global processing [2].

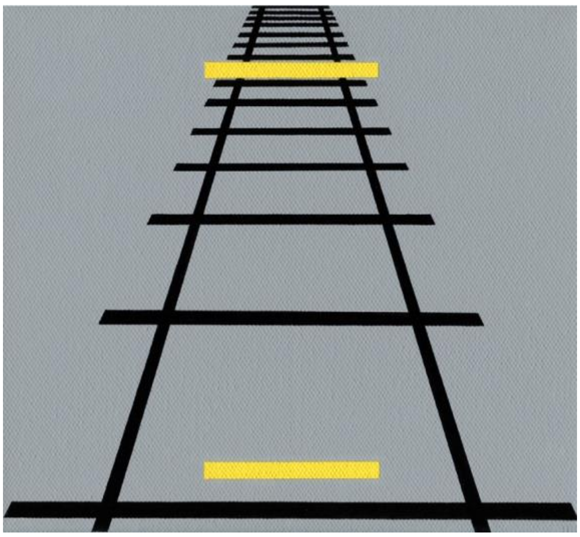
The WCC theory suggests that contextual processing deficits causes many of the impairments associated with ASD, and it could also explain the accelerated performance for some visuospatial tasks (Mottron et al., 2001). Supporters of the WCC theory argue that ASD features such as hypo- or hyper- responsiveness to sensory stimuli, extreme sensitivity to small changes in the external environment and limited interests in certain things can also be explained by this theory (Hoy et al., 2004; Vanegas & Davidson, 2015). Some of these behaviors have

[2] Local and global processing refers to hierarchical dimensions within perceptual patterns. Any spatially or temporally extended structure can be dichotomized in its embedded component or global level and its embedding components or local elements. Local and global are interdefined. The classic local- global tasks use "Navon type" stimuli, which are large patterns (such as letters) composed of small patterns of same or different nature. This concept can be applied to sensory domain, such as tactile modality, where local elements consist of hand features, shape and size and global features would be the hand after its be shape and size in reference to its space and shape.

even reported in Kanner's (1943) patient reports that described the behavioral deficits seen in autism, such has hyper- focus on small details that are insignificant.

Most of the evidence in support for the weak central coherence theory has been obtained from using visuospatial tasks to examine different processing domains in autism. These studies have used block design tasks, where individuals with autism have divided a design of a figure into its constituent parts faster than neurotypicals (Happé, 1999; Ropar & Mitchell, 2002). Furthermore, Shah and Frith (1983) found that children with autism showed significant differences compared to normally developing children in segregation abilities on the Wechsler Block Design task of the Wechsler Intelligence scale for children (Kaufman, 1983). Furthermore, individuals with both low and high functioning autism have also been found to excel at the Embedded Figures Test, where a small shape must be found inside a large shape (Happé, 1994; Hoy et al., 2004). Furthermore, individuals with autism do not use semantics or grammatical relations in memory, instead piecemeal processing is given preference over contextual meaning, such that individuals with autism will recall details of a story rather than the general story (Hill & Frith, 2003; Hill, 2004).

The results showing better performance in individuals with autism in various visuospatial tasks, suggests that individuals with autism would be less susceptible to visual illusions compared to neurotypicals (Happé, 1996). In order to succumb to a visual illusion a person must process all parts of the illusion at once, however, if an individual's processes information in parts rather than wholes, this could make them less susceptible to the illusion. Evidence of reduced susceptibility to visual illusions in ASD stems from illusions such as the Titchener illusion, where two comparison circles are identical in size, however the size of the surrounding circle creates the misperception that the comparison circles are different in size. Happé (1996) found that individuals with autism were less susceptible to this illusion, along with the Ponzo illusion and the famous Müller- lyer illusion (See Figure 1.6.1a and 1.6.1b for the description of how these illusions work) (Rajendran et al., 2014). However, Ropar and Mitchell (2001) reported that participants with autism were equally susceptible to visual illusions as TD counterparts. Using a different experimental paradigm from Happé (1996), participants were presented with the stimuli in a digital form on a screen rather than paper, they asked participants to use computer keys to adjust the stimuli to be the same size as the comparison stimuli (Ropar & Mitchell, 2001). Since then, several studies have replicated the findings of Ropar and Mitchells (2001) study and have indicated equal susceptibility to visual illusions in the ASD population (McCauley & Henrich, 2006; Woloszyn, 2010; Chouinard et al., 2013; Manning et al., 2017). Researchers have concluded that ASD population is equally susceptible to visual illusion, however, differences in experimental tasks and attention could contribute to altered susceptibility (see section 1.7 for details on multisensory processing).



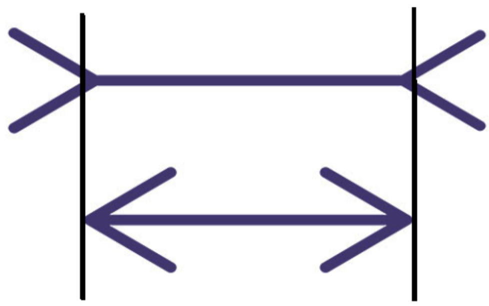


Figure 1.5.1a. The Ponzo Illusion (Mario Ponzo, 1911) is a geometrical- optical illusion. The highlight of the illusion is that the human mind judges an object's size based on its background. For typically developing individuals the illusion results in a misjudgment, however, individuals with autism are less susceptible to the illusory percept. **Figure 1.5.1b.** The Müller Lyer Illusion (Franz Carl Müller-Lyer, 1889) is another optical illusion consisting of stylized arrows. When viewers are asked to place a mark on the figure at its midpoint, they invariably place it more towards the "tail" end. The two lines are of the same length; however, they appear to be to different length due to the pointing arrows. When asked if the lengths of the two parallel lines is identical or not, TD individuals often report that they are of different lines, however, individuals with autism do not show this effect. Both these optical illusions have been used to test global vs local processing in autism. Results have demonstrated that individuals with autism process these illusions with its local aspects i.e. individual components, rather than processing the image as a whole.

Figure 1.5.1a and 1.5.1b. Illustrates the Ponzo and the Muller-lyer illusions. These 2-dimensional illusions have been used widely in the autistic population to measure visual processing. Majority of the research indicates that children and adults with autism are not susceptible to these illusions because they break the elements into components (i.e. background and lines), whereas, the typically developing population judges the illusion as a one whole stimuli and the brain compares the lines in relation to the background. Same is the case with the Müller- lyer illusion as the autistic population has been less susceptible. For example, in reference to Gestalt psychology, the autistic individuals process the local elements of any stimuli rather while showing a bias or absent global processing and this falls in line with the claims of WCC theory.

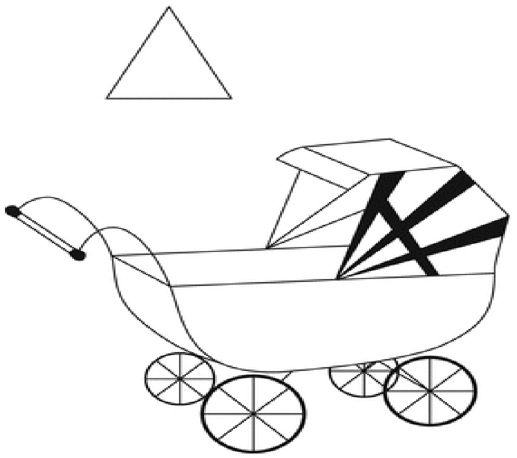
1.5.2. Enhanced Perceptual Functioning Theory

The Enhanced Perceptual Functioning Theory (EPF) is similar to the WCC theory as it states a deficit in global processing (Frith, 1989) and a detail oriented cognitive style (Frith & Happé, 1994; Happé & Frith, 2006), however, this theory of autism postulates enhanced low-level perception, without making any assumptions about quality or quantity of global processing in ASD (Mottron et al., 2006). In simpler terms, there is enhanced processing at a local level i.e. processing of lower- level sensory information (see glossary for further definition), however, they do not indicate whether it's because of a global deficit.

Evidence in support of the EPF theory of autism arises from studies that have shown superior local processing in ASD participants but have failed to display a global deficit. Local and global visual processing abilities have been assessed in autistic individuals and controls using the embedded figures task, Navon Shape stimuli and the block design task (see figure 1.6.2a and 1.6.2b). The performance on these was later correlated with scores on the Autistic Quotient (Baron-Cohen et al., 2001b)[3] .The results found a positive relationship between AQ traits and performance on all three tasks, where higher AQ scorers were more successful in task performance (Chamberlain et al., 2013). In a related study by Chen and Colleagues (2012), they measured visual perception in autism using a speed discrimination task where participants with autism spectrum disorders (n = 19) and healthy controls (n = 17) were required to detect motion speed and to detect coherent motion. The results demonstrated that individuals with ASD outperformed controls in the speed discrimination task; however, they showed poorer performance when asked to detect coherent motion. The researchers suggested that individuals with ASD showed superior local processing; however, the global deficit was only prominent when the temporal interval between events was increased (Chen et al., 2012). Therefore, the EPF theory hypothesizes that the pattern of behavior as well as the specific neural and cognitive processes in ASD are caused by more independent and enhanced functioning of perceptual processes in individuals with ASD compared to typically developing individuals (Mottron et al., 2006). Perception in ASD is characterized by a local perceptual bias and enhanced

[3] The Autistic Quotient or the AQ is a 50- item self- report measures that covers the five deficits that are related to autism: social skills, attention switching, attention to detail, communication and imagination- 10 questions related to each domain).

functioning and implication of low- level perceptual mechanisms during both sensory and cognitive tasks.



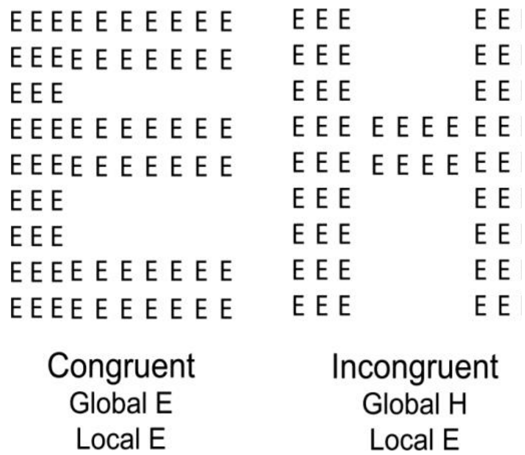


Figure 1.5.2a. Example of the famous stimuli used for the embedded figures task (Happé, 1994) - during these task participants are shown a complex design and then a simple shape (triangle). The subjects are asked to find the simple shape in its embedded form within the complex shape. **Figure 1.5.2b.** Navon task (Navon, 1977)- the basic idea of the Navon task is that when objects are arranged in groups, there are local and global features, such as in the image above the letters "E and H" has its individual features and global feathers (the alphabets made with its local features). The basic finding of the Navon's task is that people are faster in identifying features at the global level (such as letter E and H) than at the local level. Shah and Firth (1983) found that children with autism were more accurate than typically developing controls on the EFT task and the Navon's task. Furthermore, Baron- Cohen (1999) found that adults with high-functioning autism or related condition of Asperger's syndrome were also faster than normal on the adult version of these tasks.

Figure 1.5.2a and 1.5.2b illustrates two visual stimuli that are used to measure visual processing in autism, the embedded figures task and the Navon task. The results of stimuli show similar results, indicating that autistic group is less susceptible to these illusory percepts because they are processing locally rather than globally. Such as the Navon task, the typically developing individual is faster at detecting the global features of the stimuli i.e. the letter made with smaller letters (E and H), whereas, an individual with ASD processes this through its local elements. These ties with the Enhanced perceptual processing theory of autism, where autistic individuals are faster at processing local elements of a stimuli i.e. superior local processing. However, this theory does not make any claims regarding global processing in autism. The WCC and the EPF theories of autism are arguing the same cause, however, one indicates a relation towards global processing, whereas, the other one does not. However, it is important to note that, the aim of this thesis is not to compare these two theories.

1.6. Multisensory Integration in Autism

Individuals with autism tend to perform poorly during conditions that require collapsing information across multiple sense modalities, where most of the perceptual problems reported in autism are believed to be because of the failure to properly filter or simultaneous processes vision, auditory and tactile inputs (Belmonte, 2004). Most of the evidence that is in favor of this claim has been tested through sensory illusions that required proper concatenation of inputs across multiple domains and the evidence suggests that these processes operate at a different level in ASD compared to typically developing individuals. However, this effect is diminished in those with autism as they do not fall for the illusory percept due to inefficiency in collapsing visual and auditory cues simultaneously (O'Neil & Jones, 1997).

Sensory illusions relating to vision and auditory modalities are far more studied compared to other sensory domains. The flash- beep illusion is one such example of lower-level multisensory integration and it demonstrates differences in behavioral responses in the ASD population compared to the typically developing counterparts (For a full review see (Marco et al., 2011;Marco et al., 2012). Salient differences in sensory integration have also been reported at a more complex level such as during speech comprehension and production. Research indicates that when audio and visual speech are mixed and presented to those with ASD, their performance drops to chance level indicating problems associated with speech comprehension (Bebko et al., 2006). Multisensory illusions measuring linguistic performance, such as the McGurk effect, in ASD indicates that improper timing of sensory integration contributes to observable problems with communication in the ASD population. Research indicates that both neurotypicals and individuals with autism perform well on the task, NT show a greater dependence on the visual feedback of the illusion (Gelder et al., 1991; Williams et al., 2004), even after both groups are trained on the visual feedback component, individuals with ASD fail to show any improvements in performance (Smith & Bennetto, 2007; Iarocci et al., 2010). Performance on this illusion indicates a deficit in reliance on visual feedback in ASD suggesting that a failure in relying on certain "sensory cues" in challenging environments is troublesome for people with ASD.

Most research looking at multisensory integration in autism has focused on investigating how multiple sources of sensory information are combined in the visual and auditory domain due to its contribution in the visual and speech deficits reported in ASD. There is a limited number of studies that have tried to establish how visual, tactile and proprioceptive information is combined in autism. This is an important area to be studied as these form the basis of perception and action, body ownership and understanding where one's own body stands in relation to the external environment (Van Beers et al., 1999, 2002; De Gelder & Bertelson, 2003). As the main aim of the current thesis is to measure the susceptibility of individuals with high functioning autism and those with non- clinical autistic traits towards illusions involving the integration of visual, tactile and proprioceptive information, the following sections will be focusing on multisensory integration issues related to the visual, tactile and proprioceptive information.

1.6.1. Multimodal Illusions in Autism Spectrum Disorders

As close similarity between sensory processing and illusion susceptibility, it is equally important to understand these processes in individuals with autism as ASD as a condition is characterized by deficits in social processes that are readily dependent on accurate body representation. In order to understand body ownership and localization various different experimental paradigms have been used in children and adults with autism, multimodal illusions have been the most common way of assessing ownership. Within these, majority of the research has focused on visual and auditory modalities, however, limited amount of studies has investigated susceptibility to illusions that manipulate visual, tactile and proprioceptive information.

Bao et al., (2017) investigated MSI abilities in autism using lower- level stimuli that are not socio- communicative in nature by testing susceptibility to auditory guided visual illusions. Individuals with autism demonstrated susceptibility to the flash- beep illusion, however, the integration of audiovisual sensory information is less selective in autism, compared to typically developing individuals. Stevenson et al., (2014) investigated audio visual integration in individuals with high functioning autism to measure the effects on speech perception using the 'McGurk Effect'. The researchers found that the performance of the HfA group in the multisensory temporal tasks was dependent on stimuli complexity, suggesting less precise integration as the task complexity increased compared to the typically developing group. Furthermore, the strength of perceptual binding of audiovisual speech was strongly related to their low- level multisensory processing abilities, hence, indicating that deficits in lower- level sensory processing may affect higher- order domains, such as language and communication (Stevenson et al., 2014).

The Rubber hand Illusion (RHI) is often used to investigate visuo- tactile and proprioceptive integration (Botvinick & Cohen, 1998). In this experimental paradigm, through synchronous stroking of the participants' real unseen hand and a fake rubber hand, this leads to participant's reporting ownership over the fake rubber hand. During the rubber hand illusion procedure, the participants' unseen right hand is touched at the same time as they view a fake rubber hand being touched in the exact same location. The synchrony between the visual input (viewing the rubber hand and the real hand at the same time) and the tactile input (brush strokes being felt over the fake and the real hand at the same time) leads to embodiment of the fake hand. However, this is no longer applicable when the visual and tactile input is asynchronous. It has been consistently replicated in typically developing adults, where majority of them have reported the rubber hand as their own hand (Botvinick, 2004).

1.6.2. Extended Temporal Binding Window in ASD

To my knowledge, three studies have tested the susceptibility towards the Rubber hand illusion in the ASD population in order to understand visuo, tactile and proprioceptive integration directly. Cascio et al., (2012) investigated the susceptibility of children with and without autism towards the rubber hand illusion. Based on the claims made from previous investigations (Minshew et al., 2004; Glazebrook et al., 2009), individuals with ASD are less likely to integrate proprioceptive information with tactile and visual input compared to the typically developing population; Cascio and colleagues (2012) predicted that the children with ASD would be less likely to experience the rubber hand illusion following synchronous visual and tactile stimulation compared to typically developing children. Furthermore, they also tested whether the susceptibility to the RHI is related to the clinical measures of impairments in children with autism. By manipulating the time during which synchronous and asynchronous stimulation was applied over the fake and the real hand, the results showed that the typically developing children were more susceptible to the illusion, where they exhibited proprioceptive drift towards the fake rubber hand after synchronous stroking. However, children with autism were less susceptible to the illusion as they did not exhibit significant drift towards the fake rubber hand. Furthermore, the effects of the illusion occurred after three minutes of synchronous brushing on the fake and the real hand for the typically developing group, and the effects were sustained for six minutes. Children with autism did not exhibit “proprioceptive drift” during the initial three minutes of stimulation but did so after 6 minutes of brushing, indicating that they took longer to experience the rubber hand illusion compared to the typically developing group. The delay displayed by the ASD group was interpreted by the authors as due to delayed multisensory integration, as the children did not experience the illusion during the first block; however, showed susceptibility during the second block of synchronous stroking of the hands and this was due to the extended temporal binding window for visual and tactile inputs in ASD.

Evidence for an extended temporal binding window have been found for both social and non- social visual- auditory integration in autism (for e.g. Foss-Feig et al., 2010; Kwakye et al., 2011; Chevallier et al., 2015; Woynaroski et al., 2013). Furthermore, a recent study measured the temporal binding window for visuo- tactile information in adults with ASD and found no evidence for it (Poole, 2015). Therefore, most research measuring the temporal binding window in ASD is related to visuo- auditory sensory domains where studies have provided different results (van der Smagt et al., 2007).

The traditional theories of autism mainly focus on cognitive styles in ASD trying to explain deficits seen in relation to facial recognition and emotions. The extended temporal binding window in ASD has gained popularity as one of the leading theories explaining sensory integration deficits seen in autism. This theory argues that sensory binding in ASD is atypical. In the typically developing population, it is suggested that adults integrate sensory inputs with a slight temporal delay; however, this delay should be within the specific temporal binding window timeframe. Hillock- Dunn & Wallace (2012) suggested that the temporal binding window during which sensory inputs are integrated gets shorted as an individual’s age increases. However, this has not found to be the case for those with autism, as they show a reduced ability to filter which inputs should be integrated or not and it does not improve with age, resulting in extended temporal binding window (Foss- Feig et al., 2010; Kwakye et al., 2011; Stevenson et al., 2014). An extended temporal binding window could possibly contribute to the sensory issues often seen in those with autism, this is because an extended binding window of sensory inputs would lead to inappropriate integration of sensory events resulting in atypical behaviors, such as the feelings of sensory overload often seen in ASD (Rogers & Ozonoff, 2005) particularly in during those social events where there is a high degree of changing multisensory inputs. Furthermore, an extended temporal binding window can also affect higher- order social, cognitive and behavioral development. For example, communicating with a person requires a person to detect lip movements, body stance and their speech and then put them together. However, if this does not happen within the “binding window” it would affect an individual’s response, as there would be no distinction between the relevant sensory inputs (arising from the other person) and the unrelated sensory inputs arising from the surrounding environment. Evidence for this was provided by Stevenson et al., (2014) who demonstrated the relationship between temporally extended audio- visual binding window and poor speech abilities in children with ASD.

The idea that individuals with ASD have an extended binding window has the potential to support the claims made by the Weak Central Coherence Theory (Happé & Frith, 2006) as this would explain how these individuals might favor or choose to put together individual elements, hence, preferring local information over global processing. Furthermore, individuals with ASD would be more detail oriented; hence, being more aware of internal events in order to processes information selectively. This would further support the claim regarding enhanced unimodal processing abilities in autism. However, it is beyond the scope of the current research to investigate the temporal binding hypothesis of autism. However, it will be discussed as an alternative theory depending on the results obtained in general discussion.

1.6.3. Over- Reliance on Proprioception in ASD

Paton and Colleagues (2012) tested the susceptibility of adults with high- functioning autism and typically developing counterparts towards the rubber hand illusion. However, Paton et al., (2012) modified this by introducing goggles that showed the fake hand in the same spatial location as the real hidden right hand. This was done to expedite the time it takes to induce the illusion (typically three minutes for the traditional RHI) and reduce the proprioceptive incongruency between the real and the fake hand. Interestingly, the results of the study indicated that both groups, ASD and TD, reported high embodiment for the fake hand, but this was only present for the synchronous but not asynchronous condition. The TD group showed a higher embodiment during the goggles condition compared to no goggles condition, however, there was no significant difference found between the goggles/ no goggles condition for the ASD group. The authors suggested that the typically developing group, during the no goggles condition tried to integrate visual and tactile information, however, this was reduced due to the proprioceptive conflict. The proprioceptive conflict was reduced during the goggles condition, leading to more successful integration of visuo- tactile and proprioceptive information when embodying the fake hand. However, the autistic group was suggested to be more reliant on proprioceptive information in the goggle/ no goggle conditions, therefore, they showed reduced embodiment (Paton et al., 2012).

The second component of the RHI is to measure the proprioceptive drift. Proprioception is defined as the sense through which we perceive the position of our body in relation to the surrounding environment and moderate movement accordingly (Jones & Johnston, 2000). This occurs after an individual has embodied the fake hand, therefore, when asked to make judgements regarding the perceived location of the right hand their estimates are closer to the fake hand compared to the real hand. This drift only occurs after synchronous stroking of the hidden and the real hand, but not when asynchronous stroking is applied. The distance between the perceived location of the hand is often used as a more concrete and objective measure of embodiment of the illusion. The results for the proprioceptive drift in Paton et al., (2012) study indicated that there were no significant differences in the drift between the synchronous and synchronous conditions for the TD group. They displayed a higher drift towards the fake hand compared to the autistic group. Again, the authors associated this difference to be due to the ASD group not integrating visual and tactile inputs, relying only on proprioception resulting in more accurate estimates. However, there were no baseline estimates regarding hand location estimates taken prior to testing, therefore, hand localization abilities cannot be factored out and comparisons cannot be made regarding performance when little is known regarding an individual's own localization abilities. The results also showed that there was a wide variability in the drift displayed by the autistic group, where some were further away from the hand and some closer to the hand, therefore, if individuals with autism were in fact more reliant on proprioceptive information, than one would expect similar performance in hand localization across the entire sample.

Palmer et al., (2013) measured the susceptibility towards the RHI in individuals with autism and typically developing individuals with high and low autism traits (measured using the Autism Spectrum Quotient Self Report Measure- Baron- Cohen et al., 2001). The AQ is a widely used self- report measure for identifying individuals of typical development with autistic tendencies. It has been a widely used questionnaire and its reliability and validity has been tested (Simon Baron-Cohen et al., 2001a). The AQ is a 50- item self- report measure that convers the five deficits that are related to autism: social skills, attention switching, attention to detail, communication and imagination- 10 questions related to each domain). Research has also demonstrated test- retest reliability of the AQ and the AQ sum scores are normally distributed in the general population (Hurst et al, 2007). Cross cultural equivalence in different samples has also been shown (Kurita et al, 2005; Wakabayashi et al, 2006; Hoekstra et al, 2007). The cut off scores used by them for their study was 18 and above for the high AQ group and anyone scoring below was in the low AQ group.

The results from Palmer et al., (2013) did not show significant difference in proprioceptive drift between TD group with high and low AQ traits and the autistic group, however, salient differences were found between groups during the synchronous condition. This was evident in the reach-to-grasp movements (for which participants were required to reach for a cylinder placed in front of the right hidden hand). The results also suggested that compared to the individuals scoring lower on the autistic trait measure, the autistic group showed a reduced effect of context i.e. whether it was synchronous or asynchronous stroking of the hand, such that the reaching movements during both synchronous and asynchronous conditions were similar. Furthermore, the TD group seemed to only show the contextual effects of the illusion, where a conflict was found between the proprioceptive information and the illusory expectation. However, the researchers claimed that a higher reliance on proprioceptive is also evident in those with high autistic- like traits but of typical development.

A common theme prominent in both the studies (Palmer et al., 2013; Paton et al., 2012) is the idea that there is an over- reliance on proprioception in individuals with autism while disregarding other sensory inputs. Proprioception is an important sense as it modulates balance and movement and works in conjunction with other sense, especially vision and tactile inputs. Several studies have demonstrated that individuals with ASD show a bias for proprioception, compared to the other senses, or over- reply on this sense. This suggests that typically developing individuals integrate sensory information in a “statistically optimal way” suggesting that sensory inputs received from the sources will be integrated in the best possible way to execute a response (Ernst and Bulthoff, 2004). However, over- reliance on a single sensory source, such as proprioception, would lead to atypical perception. This seems to be the case in ASD, where there is a disregard of other sensory inputs but a high reliance or dependence on proprioception.

Various studies have tried to explore whether or not there is a dependence on proprioception in the autistic population and several have found evidence for a specific bias for proprioceptive inputs compared to other sensory information in autism. For example, Haswell and Colleagues (2009) children with ASD and of typical development learnt to use a robotic arm to reach for toy animals. They found no significant difference between groups during the initial rate of learning to control a robotic arm as errors in localization of toy animals decreased over trials highlighting the role of training. However, the ASD group showed to develop a much stronger association between their own arm movements and the resulting proprioceptive inputs than the typically developing children who showed a greater reliance on the integration of visual and proprioceptive feedback (Haswell et al, 2009). This finding has also been found in several other studies using similar tasks and robotics (for e.g. Gidley et al., 2008; Izawa et al., 2012). Furthermore, Izawa et al., (2012) suggested that individuals with ASD have a preference or a bias for processing proprioceptive inputs over integrating them with visual inputs. Marco et al., (2015) recently modified the robotic arm task to include trails in which reaching actions were perturbed, resulting in movement errors sensed through vision and proprioception. Over all, the results of the investigation suggested that individuals with autism may be more accurate at body localization tasks when only proprioceptive inputs are present, however, the accuracy decreases resulting in more errors when congruent visual and proprioceptive inputs are present.

The finding that individuals with ASD are better when only unimodal information is available as opposed to congruent visual and proprioceptive has not been found consistently across different studies (e.g. Weimer et al., 2001; Galea 2011). For example, studies have shown that performance of children with autism is worse than neurotypicals in tasks such as balancing on one leg, participants are required to depend on proprioceptive feedback while vision is blocked (Weimer et al., 2001). Galea (2011) assessed the accuracy of proprioceptive estimates in autistic and typically developing adolescents. Participants were required to use a joystick in their left hand to move a dot on the screen until it was aligned to be above their right, unseen index finger. The results showed no difference between the groups on estimation accuracy in any of the tasks. Therefore, providing support for many anecdotal reports that suggest impaired ability to use proprioception in daily tasks, such as pointing, and reduced awareness of body movements and position (Biklen et al., 2005).

Findings regarding overreliance on proprioception in autism have not been consistent, where majority of the studies that have found support for this claim have used similar tasks and have mainly tested children, therefore, cohesive conclusions cannot be made (see Galea et al., 2011; Weimer et al., 2001). Due to the variance in the results and the sample studied (i.e. as autism lies on a spectrum, the severity of sensory symptoms varies between individuals), it is possible that there is a different explanation for atypical MSI, which manifests itself as over-reliance on proprioception, and is very context dependent and is only evident in certain situations.

Cascio et al., (2012) argue that children with autism are susceptible towards the RHI; however, they require a longer time in order to embody the fake hand. Whereas, Paton et al (2012) and Palmer et al., (2013) argue that the susceptibility to the rubber hand illusion is decreased because they tend to over rely on proprioceptive input, therefore, disregarding the visual and tactile feedback that is necessary for the embodiment of the rubber hand. The RHI requires an individual to give ownership to, or embody, a fake rubber hand by disregarding the various physical dissimilarities between their real hand and the fake hand, such as size, texture and shape (Tsakiris & Haggard, 2005), only after an individual has embodied the fake hand, and they display a drift towards the fake hand during the reaching task. These inconsistencies between the real hand and the fake hand are minor factors when introduced to the typically developing population as these individuals have intact imaginary abilities and they are able to overcome these. However, these differences could be exaggerated in those with autism since research has showed multiple times that they inherit a very detailed- focused style of processing. Furthermore, imagination is a core deficit of autism (Happé, 1999; Baron-Cohen et al., 2001a; Happé & Frith, 2006; APA, 2013a). Together the detail oriented cognitive style and imagination deficit could also affect susceptibility and embodiment of bodily illusions.

Autism as a condition is a cohort of different problems that are present in those with a diagnosis. It is well established that symptoms of attention deficit disorder are highly prevalent in those with autism (Leitner, 2014). It could be that group differences between those with autism and of typical development are due to the lack of attention given to the fake hand by the autistic group. It is understood that in order for the illusion to work, one needs to pay attention towards the rubber hand for a significant length of time, therefore, decreased attention towards the fake hand could contribute towards the reduced susceptibility. However, this has not been directly tested in any of the ASD research using the rubber hand illusion. Individuals with autism are highly sensitive to tactile stimuli; therefore, it can also be argued that the tactile stimulation during the rubber hand illusion (brush strokes on the real hand) could have distracted the participants from primarily focusing on the tactile input rather than the visual feedback. Hence, reducing embodiment of the rubber hand illusion.

Alternatively, many of the studies mentioned above have diversified their findings towards understanding sensory integration at an experimental level, many have not interpreted their findings in terms of top- down and bottom- up contributions towards perception in general, but in terms of lower- level sensory processing and higher- level cognitive contributors linking it back to the weak central coherence theory. The mechanisms underlying these processes is extremely important as most of the recent theories of autism can be compared in terms of top- down and bottom – up processes. Unlike many other theories, the concept of top- down and bottom up process is based on a very systematic gradient. In psychology, there are two general processes involved in sensation and perception. Top- down processing refers to perception that is driven by cognitions i.e. your memory or knowledge, whereas, bottom- up processing refers to processing sensory information as it is being introduced in the external environment i.e. sensations of touching a keyboard or smelling a familiar smell that you have smelt before. This systematic review runs a bidirectional path, where one process updates the other to implement, almost like a constant updating loop of information that is new and or old. For example, accurately and efficiently perceiving social cues such as body movement and facial expressions is extremely important in social interaction as it would help us interact with the physical environment. However, this is the case in normal development. Perception of patients suffering from schizophrenia and individuals with autism do not implement these strategies in the right way. Therefore, one could assume that the constant feedback loop that is active in normal development is absent or atypical and runs in a different way.

Research looking at these processes in autism has highlighted several aspects that could explain the contributions of top- down and bottom- up processes in autism. Several researchers have argued that atypical top- down modulation of early sensory processing is common in autism. Bird et al., (2007) used fMRI to record brain activity of individuals with HfA, ASC and neurotypicals during an attentional task involving face processing. The results demonstrated that neurotypical's attention modulated activity in the fusiform face area (FFA), such that activity was high in FFA when attention was directed towards the face and low when attention was directed someplace else. However, the autistic group did not show similar activity in the FFA as they did not show a variation in activity level when the attention was directed or not (Cook et al., 2012). The researchers concluded by suggesting that there is atypical top- down modulation in autism. It is well understood and studied that the distinction of top- down and bottom- up information is simpler for two- dimensional stimuli as it is easier and more direct. Studies have used 2- dimensional stimuli such as embedded figures task and the block design task, to interpret visual dominance over cognitive reliability in typically developing individuals, patients with schizophrenia and individuals with developmental disabilities such as autism. For example, the block design task, which is a subset of the Wechsler Intelligence scale (Wechsler, 1981) in which two- color pattern is constructed from a number of identical two- color blocks. Shah and Frith (1993) used this procedure to test twenty autistic participants and healthy controls. The autistic group was significantly faster and were more accurate in the completion of the task, where they successfully and quickly recognized the design within the larger shape. Initially, the results of this investigation were discussed under the idea that individuals with autism possess a greater aptitude for breaking patterns into separate wholes without being influenced by the whole shape of the stimuli- or an ability to “segment a gestalt” (Shah & Frith 1993). Since the conception of this theory, the theory itself has seen several revisions Happé & Frith (2006) suggested that autistic children showed reduced global processing and superior local processing and then a shift towards a tendency for featural, rather than an integrative processing Happé & Booth (2008). However, in 2012 Frith suggested that the top- down control of the flow of information is weak in autistic individuals and this weakness reduces the influence of prior expectations, hence, indicating that the bottom- up sensory processes are relatively stronger in autistics (Frith, 2012). Therefore, to simply this, top- down and bottom- up processes complement each other by working together to aid in perception, however, in autism there seems to be weakened top-down influence, but an over active bottom- up stream of information. This idea can explain why several individuals with autism are better at various sensory tasks.

Bayesian psychologists have tried to explain perceptual and sensory differences in autism by using the Bayesian decision theory (Pellicano and Burr, 2012). Using this theory, prior knowledge about the world or a stimulus (in experimental settings) can be represented as probability distributions[4], and the researchers have argued that autistic individuals may have poorer prior distributions compared to healthy people. In response to Pellicano and Burr’s (2012) suggestion, Van de Cruys et al., (2014) provided evidence in favor of their theory and indicated that through this framework, we can understand the perceptual differences in individuals with autism, however, they suggest that instead of a poorer prior distribution of top- down knowledge, autistics represent an overly- active prior distributions. However, what is of interest here is that both ideas, whether imprecise or overly precise, top- down processes would produce the same results, which in the case of autistics would be a mismatch between

[4] In Bayesian framework, prior knowledge and observation can combine to yield percepts. Using this theory, prior knowledge about the structure of the world or a stimulus (experimental settings) can be represented as probability distributions or “priors”.

sensory and prior information, with a greater reliance on sensory information rather than contextual processing (Lawson et al., 2014). But, this exact idea describes the central idea of the WCC theory, where it states that altered top- down processing leads to a bias towards bottom- up processing. Therefore, as the current thesis involves typically developing individuals, the results gathered in this thesis will be discussed under Bayesian theory of sensory integration and the core concepts of the theory will be used to explain the results gathered from both populations studied in the general discussion.

It is very unclear whether the reduced susceptibility often reported in the autistic population is because of the physical characteristics of the illusion or in fact it is due to individuals with autism not integrating visual and tactile information and heavily replying on proprioception. It is extremely important to conduct more studies measuring the susceptibility to the multisensory illusions where more realistic illusions are delivered, therefore, the MIRAGE mediated reality device (Ratcliffe & Newport, 2017) serves as a great tool to measure susceptibility towards multisensory illusions due to its unique characteristics and its ability to clearly define the top- down and bottom-up aspects of the illusions.

1.7. Cognitive Vs Sensory Theories of Autism

Four major theories have been discussed thus far in this thesis that are most relevant to the context of my research. The two more traditional theories, i.e. weak central coherence theory (Frith & Happé, 1994) and the enhanced perceptual theory (Mottron et al., 2001), argue how various social and non- social deficits in autism are due to a specific cognitive style of processing various forms of information. On the other hand, over- reliance on proprioception (Wallace & Stevenson, 2014) and temporal binding window (Foss-Feig et al., 2010) are two of the latest theories explaining how sensory deficits in autism are due to atypical sensory integration. The WCC theory argues that problems with global processing in individuals with autism can only allow them to focus on the local elements in a very accurate way, whereas, the EPF theory indicates that better function and increased independence of perceptual processes (such as visual or auditory processes) are responsible for the unique pattern of cognitive, behavioral and neural performance observed in autism. Over- reliance on proprioception argues that sensory integration in autism is weak due to an inherit disposition of the autistic person to rely on proprioception, while disregarding other sensory inputs, therefore, resulting in the various social and verbal deficits reported in autism. Lastly, the temporal binding window hypothesis argues that the integration of sensory inputs takes a longer period of time compared to typically developing individuals, hence, arguing a wider window during which two different inputs are integrated together.

The WCC theory and EPF theory take a more cognitive approach towards explaining perceptual deficits in autism. There are two processing hierarchies, i.e. lower- level sensory integration and higher- level cognitive processes, and these theories argue that individuals with autism tend to focus on the local details rather than the global picture. Most of the evidence for these theories arises from performance on visuo- spatial tasks, such as visual illusions, during which individuals with autism outperform control participants showing lower levels of susceptibility. Hence, indicating superior lower- level processing while ignoring the global percept. Superior lower- levels of processing indicates better performance at sensory tasks, therefore, indicating that individuals with autism are processing sensory information but they do not integrate it with higher- levels processes to formulate a global percept. The two new theories of sensory processing in autism are both sensory- driven, where one argues that there is an over- reliance on one input more than the other and the second one indicates that the timing during which sensory inputs are combined together, it differs in those with autism as they show that they require more time to integrate two inputs compared to typical controls.

A common theme amongst all these theories is that they all indicate that there is an element of underutilization of internal knowledge or cognitive knowledge about themselves, which limits an individual's ability to formulate hypotheses, make adaptive predictions and interpretations of the world. At the core of it, all the aforementioned theories argue that individuals with autism tend to show superior lower- level performance while the integration of the lower- level sensory information with higher- level cognitions is not the same as it is with TD individuals (Frith, 1989; Ropar & Mitchell, 1999; Kern et al., 2006; Hames et al., 2016; Pellicano & Burr, 2012) . The more traditional theories of autism and perceptual processes make claims for higher- level cognitive processes, whereas, the latest theories argue that there are issues with sensory integration in autism, however, they do not really consider how the sensory information is weighed against an individual's top- down knowledge regarding the world around them. Similarly, the two newer theories of autism are again both sensory driven as they argue that individuals with autism show superior performance at sensory level, however, they do not make any specific claims regarding how the sensory information is integrated with top- down knowledge regarding one's body (Balasco et al., 2020). Studies that have tried to measure these hypothesis of sensory processing in autism have suggested that bottom- up processing seems to be superior in autism, however, little to know explanations have been given as to why and how the top- down processes work (Foss-Feig et al., 2010; Cascio et al., 2012; Palmer et al., 2013; Greenfield et al., 2015).

A core feature amongst all these theories is that they all indicate superior processing of sensory information in autism while claiming that problems arise in integrating the sensory information with existing cognitive knowledge. All these theories on their own make sense such that, the temporal binding window argues that sensory stimuli that occurs in close temporal proximity are more likely to be integrated, however, if there is a delay or alterations in this window it could give rise to a blurred, unpredictable sensory environment. The WCC and EPF tell us that individuals with autism tend to have a more fragmented approach towards the world (with focus on individual components of the environment). Therefore, low- level sensory perception is enhanced with deficits in sensory integration, leading to a fragmented view of the world. Therefore, throughout development this could lead to an over specialization for only perceiving the primary sensory cues at the expense of the more complex sensory cues resulting in differences in sensory processing in autism. Lastly, over- reliance on proprioception focuses on "atypical hierarchical information processing" as the base of social deficits seen in autism. In order to adequately perceive the world around us, humans use both incoming sensory information (bottom- up processes) and inference from prior experience and context (top- down processes). However, this theory argues that in autism, there is an over-reliance on the bottom- up processes without any integration with top- down processes. Therefore, in order to test these theoretical accounts, we would be conducting a series of experiments in order to see which account could explain the obtained results. However, it is important to note that sensory integration is an extremely complex processes that is initiated with a physical stimulus but has its roots deep in various neurological processes. Especially when testing somatosensory integration several factors play a role, such as the skin where the physical stimuli first comes in contact to the individual all the way to the neural pathways that travel this information to the brain. Hence, disturbances in any of these stages could produce abnormal sensory reactions (Balasco et al., 2020). Therefore, it is the aim of this research to only understand sensory integration at the basic level, however, it is far beyond the scope of this thesis to investigate what happens at the neural level.

1.8. The MIRAGE Mediated Reality Device

It is well understood that multisensory integration plays a very important role the development of various social and non- social processes of an individual. It is crucial for interacting with the environment and provides several behavioral and perceptual benefits as opposed to unisenory processing. It is also very well understood that adults of typical development integrate sensory information in a statistically optimal manner, where research has showed that susceptibility to sensory illusions is a healthy part of perception and the current sensory information is integrated with top- down knowledge which leads to perception. However, what is unclear is whether same processes underlie illusion susceptibility in those with autism. The importance of studying this in the autistic population is even more important as atypical sensory integration may underlie the various behavioral, cognitive and social deficits that constitute the condition.

The experiments in the current thesis were all conducted using the MIRAGE mediated reality device (Newport et al., 2010). The MIRAGE is a multisensory illusion box that enables an experimenter to present realistic sensory illusions to an individual's own limbs. This system uses two rectangular horizontal mirrors that are suspended equidistant between the work surface and above the computer screen that is placed in the middle of the system. The mirror reflects live video images of the participant's hands that are displayed on the computer screen. These video images are viewed in real- time by the participants as if they are viewing their hands directly in the same spatial location as their real hands and from the same visual perspective. Furthermore, with custom made hardware and in-house software, the video images of the participants hands can be visual manipulated with a millisecond delay that is not detectable.

The MIRAGE has been widely used before to understand the underlying mechanisms of multisensory integration in both typically developing individuals and those with various conditions. For example, Newport et al (2010) visually duplicated the hands of participants to investigate how changes in hand movement can affect ownership of your own hand. It has also been used to show how disrupting embodiment is effected when an individual's fingertip is visually detached (Newport & Preston, 2010). Furthermore, the MIRAGE has also been used to present participants with an illusion that suggest that their right hand has disappeared from its previously seen and felt position (Newport & Gilpin, 2011) and various other investigations (for review see: Bellan et al., 2015; McKenzie & Newport, 2015;Newport et al., 2015).

The MIRAGE mediated reality system has been used to directly investigate the two most recent theories of sensory integration in autism: over- reliance on proprioception and the temporal binding hypothesis (Greenfield et al., 2015) by manipulating proprioceptive location of the limbs and visuo- tactile synchrony in children with and without autism. With the use of the MIRAGE system, participants were presented with two identical live video images of their hands, where one was in the same location of their actual hidden hand and the other was displaced to the right or the left of the other hand. Brush strokes were applied to the children's actual hidden hand, while the children viewed the two virtual hands being stroked at the same time and they were asked to identify their actual hands. The rate at which brushstrokes that were applied to the hands were manipulated to three different temporal delays that were applied to the hand that was in the same location or the one that was displaced, resulting in only one hand had synchronous visuo- tactile inputs. The results of their study showed that visuo- tactile synchrony overrides incongruent proprioceptive inputs in the typically developing children but not for those with autism. It was hypothesized that if there is a fundamental over reliance on proprioception in autism than children would choose their correct hand across all conditions, however this was not found. Furthermore, with an increased delay length (the delay in the brushstrokes), autistic participants did in fact embody the synchronous hand in congruent conditions due to the combined weighting of visual, tactile and proprioceptive inputs.

Therefore, compared to typically developing children the autistic group needs a longer delay between the synchronous and asynchronous inputs before they can clearly identify the synchronous hand suggesting a weak and an extended sensory binding. Hence, this study provides the first evidence for an extended sensory binding window for visuo- tactile information in autism (Greenfield et al., 2015).

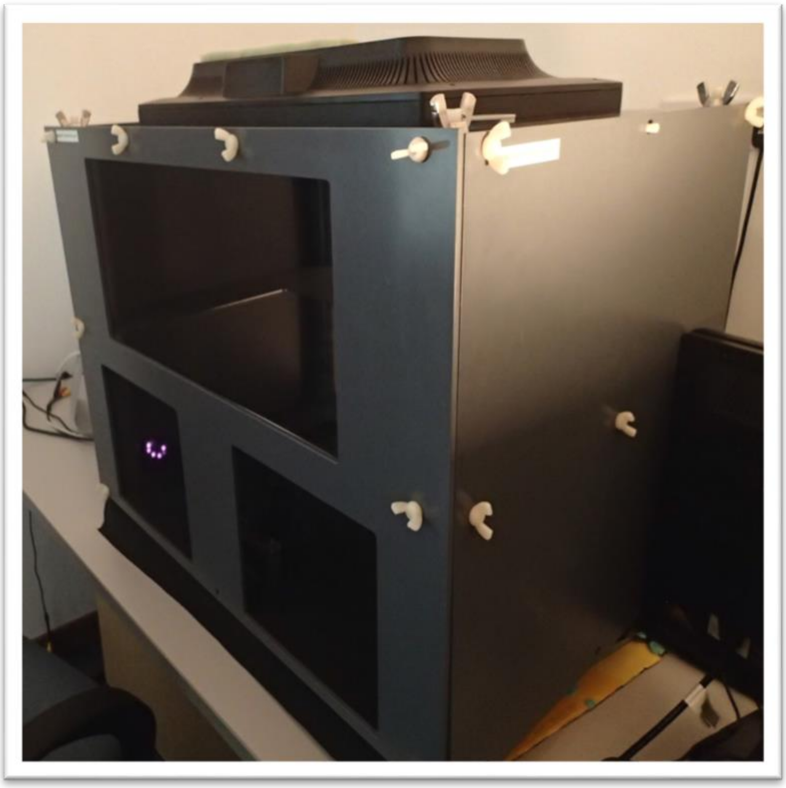


Figure 1.3. The MIRAGE multisensory illusion box (Newport, 2010). This illusion box was used to present participants with realistic sensory illusions on the participants own limbs. This system uses two rectangular horizontal mirrors that are suspended equidistant between the work surface and above the computer screen that is placed in the middle of the system. The mirror reflects live video images of the participant's hands that are displayed on the computer screen

1.9. Aims of the Current Thesis

Understanding sensory integration in autism is extremely important and one way of doing so is by measuring the susceptibility of the autism population to more realistic multisensory illusions that manipulate visual, tactile and proprioceptive sensory information. Therefore, the overall aim of the current thesis is to measure the susceptibility of individuals with high- functioning autism to a set of illusions that are presented on their own limbs. Due to the novelty of the tasks used in the current thesis, individuals of typical development with high and low numbers of autism traits also experienced the same illusions to compare the performance of the two groups given the similarity between the cognitive and behavioral traits between those with autism and individuals with autism traits.

Research demonstrates that autism as a condition lies on the extreme end of a continuum, where those with high and low autism traits are present in the general population, but are not on the extreme end of the spectrum to warrant a diagnosis of autism (Baron-Cohen et al., 2001a; Lundqvist & Lindner, 2017). Furthermore, various studies have also found close similarity in behaviors and cognitive profiles of individuals with autism and those with high autism traits but of typical development (Hoekstra et al. 2007; Robinson, 2011).

The Autism Spectrum Quotient is one such test which has been used to measure the number of autism traits in individuals of typical development. Furthermore, it has also been used to screen clinical samples (Woodbury-Smith et al, 2005) and to predict performance on several cognitive tasks (Stewart et al, 2009), social cognition (Baron- Cohen et al, 2001b), spontaneous facial mimicry (Hermans et al, 2009), gaze preference to social and non- social stimuli (Bayliss et al, 2011), and auditory speech perception (Stewart and Ota, 2008). Palmer and Colleagues (2013) measured the susceptibility of individuals with high and low autism traits towards the rubber hand illusion. The researchers found close similarity in susceptibility and behavioral performance between those with high autism traits and individuals with high-functioning autism, suggesting that individuals with a diagnosis and those who have high number of autism traits share similar behavioral and cognitive profiles (Palmer et al., 2013).

Previous research has shown that individuals with autism tend to show superior lower-level performance when tested against unimodal illusions. Therefore, in the current thesis, I will first examine how susceptible participants with high and low autism traits (chapter 2) and individuals with a clinical diagnosis of high- functioning autism (chapter 3) are to the crawling skin illusion using MIRAGE. This illusion is a purely visual illusion that has previously shown to create visually induced somatosensory sensations in the absence of any tactile input. This was conducted to explore whether individuals with autism traits and those with HfA are more reliant on their existing knowledge regarding their limb rather than the visual input and to explore whether individuals with autism traits and HfA show high ownership over the limb when viewed through the MIRAGE. I will next examine whether participants with high and low autism traits (chapter 4) and those with a clinical diagnosis of autism (chapter 5) are susceptible to a finger stretching illusion that manipulates visual, tactile and proprioceptive information in order to test whether these individuals rely on a single sensory source more when multiple sensory inputs are provided. Objective (estimation task) and subjective ratings (illusion ownership and strength) will be obtained. Objective measures are a key aspect of this research as subjective ratings only reflect choices, whereas, objective measures i.e. estimation tasks, can tell us whether individuals with autism embody the illusion or not. It is expected that the high AQ group and HfA group would be less susceptible to the visuo- tactile synchrony compared to the typically developing and low AQ groups, hence, making more accurate finger estimations, as this is line with previous research which indicates superior lower- level sensory performance. In Chapter 6 and 7, both groups will be presented with hand localization task using a visuo- proprioceptive illusion. During this illusion, participants were required to make estimates regarding the location of their right index finger when vision and proprioceptive information regarding the hand were congruent and when it was manipulated. If individuals with autism/high autism traits show an over reliance on proprioception, as claimed by recent theories of autism and sensory integration, they should make fewer localization errors (i.e. be accurate in locating the finger) compared to the typically developing groups.

In order to further explore the performance of those with autism traits and high-functioning autism, I will be measuring the susceptibility of individuals with high and low autism traits, measured by the Autism Spectrum Quotient (Baron- Cohen et al, 2001), towards multimodal illusions that measure visual, tactile and proprioceptive sensory information. Studying the performance of those with high and low autism traits can provide insight into how they relate to mental processes (Kuo et al, 2014) and individual differences in characteristics. Studying clinical populations often times results in smaller sample sizes, therefore, screening for autism traits in the general population and measuring their performance on similar tasks may be helpful in epidemiological research because it may provide the necessary sample size to investigate the relationship between autistic phenotype severity and other theoretically important factors. Examining autism traits in the general population samples can serve as 'analogue studies' for autism, providing access to larger, more easily accessible samples (e.g. Kunuhira et al, 2006; Jackson and Dritschel, 2016).

Chapter Two

Experiment One

Crawling Skin Illusion Susceptibility in individuals with high and low Self-Rated Autism Traits

2.1. Introduction

Most of the research, investigating unimodal processing have employed 2- dimensional static stimuli and the distinctions they have used has been interpreted from the viewpoint of local vs global processing (Firth, 1989; Happé, 1999; Mottron et al, 2001; Plaisted, 2001; Maekawa et al., 2011). Alternatively, the concept of top- down and bottom- up attention could contribute to the atypical visual processing reported in individuals with ASD; however, limited studies have tried to understand perceptual processing in terms of top- down and bottom- up information processing. Previous research has suggested that lower- level visual information processing may be affected in autism (Hoeksma et al., 2007; Deschamps et al., 2007; Maekawa et al., 2011), however little is known about the effects of selective attention, whereby a subset of input is selected preferentially for further processing. This consists of two major parts: (i) bottom- up attention which is driven by properties of the stimuli and (ii) top- down attention which involves the volitional focusing of attention on a location or object based on behavioral goals (Caminha & Lampreia, 2012). Therefore, with this idea in mind, research findings related to top-down and bottom- up processes have suggested that people with autism would be better at sensory driven tasks but would fail to integrate the incoming sensory input and integrate it with their existing knowledge, failing to attenuate to the global percept. Therefore, the current study is focusing more on understanding the reliance on existing knowledge regarding their limb when processing incoming visual information.

A major part of this research stems from the idea that autism traits vary meaningfully amongst the typically developing population, where those who meet a complete diagnosis of ASD are situated at the extreme end of the spectrum (Happé et al., 2006; Mandy & Skuse, 2008). The scores typically found for measures for autism traits, such as the Autistic Spectrum Quotient (AQ) (Baron- Cohen et al., 2001) in large population samples tend to be compatible with this hypothesis (Baron- Cohen et al., 2001; Constantini & Todd 2003; Posserud., 2006). Happé (1999) presented evidence that the cognitive style in autism is part of a broader autism phenotype and can be observed in clinically healthy individuals. Furthermore, previous literature suggests there is a high degree of similarity in performance on various sensory tasks in typical individuals with high autism tendencies and those with a clinical diagnosis of autism (e.g. Walter et al., 2009; Donohue et al., 2012).

Research looking at sensitivity and attentional selection to external sensory information has been investigated using cross- modal manipulations which induce illusionary experiences within the autism population and individuals with autism traits to understand patterns of perceptual processing (Cascio et al, 2012; Paton et al., 2012). The Rubber Hand Illusion (RHI) investigates the interplay between vision, touch and proprioception that ultimately leads to the experience of owning a fake rubber hand (Botvinick & Cohen, 1998). Paton et al., (2012) tested individuals with high- functioning autism (HfA) using the rubber hand illusion (RHI) (Botvinivk & Cohen, 2001) and compared their performance to a typically developing comparison group. The results of the study outlined various visuo- tactile and proprioceptive differences between the two populations. Overall, individuals with HfA did report the subjective effects of the illusion, however, they did not show the same overall sensitivity to visuotactile- proprioceptive discrepancy between the rubber hand than the comparison group however, they displayed a reduction in the drift towards the rubber hand, indicating superior proprioceptive performance (Paton et al., 2012). This was interpreted by the researchers as "superior proprioceptive abilities" in the HfA group. The same group of researchers extended this line of investigation into the broader population, arguing that sensory characteristics associated with autism may vary together with nonclinical differences in others with autism traits (Palmer et al., 2013) and tested their performance on the RHI using the similar paradigm. The results of their investigation were quite similar to the previous study (Paton et al., 2012), indicating that participants did report the subjective effects of the illusion concerning visuo-tactile integration; however, those with higher number of autism traits, as measured using the

AQ, showed a reduced sensitivity to the presence of the illusion in their estimates of arm position and in reaching movements, indicating superior proprioceptive performance.

One heavily studied area in autism is visual perception. Although, atypical communication and social cognition are highlighted as the core deficits in autism, ample amounts of evidence exist which indicates abnormalities in low- level visual perception (such as: Happé, 1991; Dakin & Firth, 2005; Mottron et al., 2006; Simmons et al., 2009). Visual illusions have been widely used to study visual perception and attention in autism, however, it is still unclear whether the perceptual bias for local processing (i.e. details of an image) over global processing (i.e. image as a whole) is the reason why individuals with autism are less susceptible to visual illusions, which forms the hallmark of the Weak Central Coherence Theory (WCC) (Frith & Happé, 1994). This theory indicates that problems with global processing in autism might allow them to focus and pay attention to the local elements of a stimuli in a very accurate way. Happé (1996) was the first to investigate the susceptibility of individuals with autism towards six geometrical illusions; the Ebbinghaus illusion, Müller- lyer illusion, Poggendorff illusion, Hering illusions and Kanizsa triangle. Happé (1996) reported that children with autism were less susceptible towards these illusions compared to both controls and a group of children with learning difficulties. These results were interpreted in favor of the WCC theory. Since then, several researchers have tried to investigate these illusions in individuals with autism, however, some have reported that the autistic population displays equal susceptibility towards visual illusions compared to their typically developing counterparts (See: Ropar & Mitchell, 1999; Ropar & Mitchell, 2001, Hoy et al., 2004; Russo et al., 2010; Milne & Scope, 2008), whereas, others have found that children and adults with autism are indeed less susceptible to visual illusions (See: Bölte et al., 2007; Stroganova et al., 2007; Walter et al., 2009; Michel et al., 2003; Chouinard et al., 2013). In summary, differences in susceptibility have been associated with methodological differences, variations in instructions provided, differences in sample sizes and the heterogenous nature of autism itself.

Previous research has tried to investigate perceptual processes using multimodal illusions that involve an interplay between top- down and bottom- up processes, however, where studies measuring unimodal processing in people with autism or individuals with high autism tendencies is very limited. Studies have used 2- dimensional, geometrical stimuli to measure local and global processing in autism (i.e. Navon Shape stimuli and embedded figures task), suggesting a general bias towards local processing at the expense of the global context. Therefore, in the current study we examined the susceptibility of individuals of typical development exhibiting high and low autism tendencies to a visual illusion in order to examine the influences of bottom- up processes when interpreting conflicting visual information using an illusion that presents somatic sensations on the skin in the absence of any tactile input through visual manipulation. Furthermore, compared to previous studies using multisensory illusions that are dependent upon bottom- up and top- down processes (such as the RHI; Paton et al., 2012), the current illusion manipulates the knowledge of one's own hand using visually induced somatic sensations. This unimodal illusion creates a pixelated appearance on the skin of the participant's right hand resulting in reports of feeling somatic sensations in the absence of any tactile input after viewing the hand under these conditions for a few minutes.

This novel illusion has been found to increase the awareness of more ambiguous bodily sensations (McKenzie & Newport, 2015) thus creating false illusionary somatic sensations in participants with medically unexplained symptom tendencies. McKenzie & Newport (2015) used the "*crawling skin illusion"* in a sample of typically developing population reporting high and low traits associated with medically unexplained symptoms (MUS) measured through the somatoform disassociation questionnaire (SDQ- 20). Participants in their study viewed a real time video image of their own hand and in two digitally altered views: (i) in a darker luminance or in a (ii) pixelated condition (crawling skin). They recorded participant's subjective ratings during each of the visual condition. The findings suggested participants scoring higher on the somatoform disassociation questionnaire were susceptible to somatic sensations across all visual manipulations and felt lower ownership towards their viewed hand. Furthermore, independent of their scores on the SDQ- 20, they found that respondents reported higher number of somatic sensations across all conditions, suggesting an over- reliance on top- down processes when assessing internal, ambiguous bodily sensations. However, for the current research the crawling skin illusion will be used as a simple visual illusion, whereby, the visual manipulation over the participants limb would be categorized as bottom- up information. This is to test whether individuals with autism traits would be susceptible towards the illusory percept when incoming visual information is manipulated or not.

Through the manipulation of visual information, McKenzie and Newport (2015) demonstrated that individuals of typical development reporting high and low MUS tendencies over- rely on top- down processes. This was achieved by manipulating the video image of the participant's right hand so it appeared pixelated. Compared to other bodily illusions, where individuals are required to incorporate an external object, the MIRAGE system allows the manipulation of the participants own limbs. This provides us with greater means of studying limb ownership i.e. the level to which an individual believes that the limb is a part of their own body, enabling more realistic manipulations in order to understand perceptual processes in populations that have been associated with an imagination deficit. Therefore, in the context of the current research, the crawling skin illusion will be used to measure visual susceptibility in individuals with high and low autism traits.

Previous research using the RHI suggests that similar to individuals with an autism diagnosis, individuals with high autism traits display an over- reliance on sensory inputs but weak top- down modulation but to a lesser severity. However, unlike the RHI, the current illusion does not involve interplay of various sensory inputs (such as vision, touch and proprioception). Multisensory illusions typically stimulate more than a single sensory domain; it could be that when sensory inputs are stronger individuals with autism make judgements based on a singular or multiple sensory input by discriminating between sensory inputs. However, to begin with, the current study investigated the susceptibility of individuals of typical development with high and low autism traits to the crawling skin illusion[5] (McKenzie and Newport, 2015). Research indicates individuals with MUS are hyper- vigilant when assessing their internal bodily sensations resulting from dysfunctional modulation of interoceptive sensory signals by top- down cognitive processes. While McKenzie and Newport (2015) interpreted their results in relation to MUS, we will be assessing if individuals with various autism tendencies are susceptible to an illusion that presents illusionary somatic sensations (through visual manipulation) altering their existing knowledge in regards to their limb. Given the nature of the illusion and the findings demonstrated in their investigation, we hypothesized that if individuals with higher autism traits are more top- down driven when assessing incoming visual information, we would expect higher degrees of limb ownership depending on the condition they view their hand in: baseline should produce the highest followed by the other two conditions and lesser number of illusionary somatic sensations, especially in the static condition. However, if they are more sensory driven (visual information), we would expect the high AQ group to report the illusion during the crawling skin condition. Whereas, those scoring lower on the AQ would be susceptible to the illusion and report higher amounts of illusionary somatic sensations. This is due to the clash between the individual's knowledge regarding their own hand and what they are viewing, where the later carries more weightage. As this illusion has never been used in such a population before, these hypotheses suggested are based on the idea (i) there is higher bottom- up reliance in

[5] The crawling skin illusion will be referred to the static hand illusion from here on.

autism (Summerfield & Egner, 2009; Whyatt & Craig, 2012, Cook et al., 2012; Amoruso et al., 2019) and secondly, there is superior unimodal processing in individuals with autism (Blakemore et al., 2006; Leekam et al., 2007; Marco et al., 2011) and they vary across the spectrum. This would further help us understand whether individuals with high autism tendencies are more sensory driven when assessing incoming visual information, as witnessed in previous research using static stimuli.

2.2 Method

2.2.1 Design

A 3 x 2 mixed design was used in the current study, in which conditions (veridical (baseline), darkened and crawling skin) were the within- item factors and the groups (high AQ and low AQ) were the between- group factors. The dependent variable being participants' subjective ratings of the hand during the visual conditions.

2.2.1 Participants

In order to recruit participants that fit the requirements, an online questionnaire was distributed amongst all the departments at the University of Nottingham using Qualtrics (https://www.qualtrics.com/). A total of 175 responses were collected but only fifty right-handed participants (undergraduate and postgraduate students) were selected and called to complete the second part of the study[6]. All participants were screened to determine their

[6] A total of 175 responses were gathered through Qaualtrics. Follow up emails were sent to the participants out of which 93 responses were received. Due to the pre- set High AQ score criteria, a total of 45 participants were called in to take part in the study. However, on the day of testing 10 participants informed the researcher that they had already taken part in studies using the MIRAGE system, therefore, they did not take part in the study. The rest were a no show. Resulting in a total of 25 participants in the high AQ group.

handedness by using a modified version of the Edinburgh handedness Inventory (Oldfield, 1971)[7], and only right-hand dominant participants took part in the current study. The assessment of handedness was controlled for because past literature suggests that an individual's non-dominant hand tends to have decreased sensitivity to somatosensory stimuli compared to a person's dominant hand. All participants were aged between twenty- one and twenty- five years old (Mean age: 22 years and 2 months, SD: 0.94). Written and informed consent was obtained prior to participation. All participants reported normal or corrected to normal vision, and no sensory deficits.

Participants were allocated into two groups: HighAQ group or LowAQ group based on their scores on the Autism Spectrum Quotient (AQ) (Please see appendix 1.1 for the full version of the questionnaire). The AQ is a self- report questionnaire that is used as a screening measure for the symptoms of autism, consisting of 50 individual statements derived from five categories of skills known to be affected in autism. The AQ has proven to be particularly useful in demonstrating how the continuum of autistic- like traits in the typically developing population related to visual processing (Sutherland & Crewther, 2010), attention (Bayliss et al., 2011) and social cognition (Baron- Cohen et al, 2001). Each item in the AQ consists of a statement, such as "I prefer to do things with others rather than on my own". Respondents rate their level of agreement or disagreement with each statement on a 4- point scale. The range for possible scores is in between 0 – 50 with higher scores indicating greater similarity to traits of autism (Palmer et al., 2013). Participants scoring a total of 32 and above were allocated to the high AQ group in the current study; this cut off score was similar to Baron- Cohen et al's (2001) study. It has been suggested that behavioral similarities between individuals with a diagnosis of autism and typically developing individuals are more apparent above the score of 32 on the

[7] EHI is a handedness inventory that measures a person's usage of their right hand in everyday activities. This is a self- report measure and does not guarantee handedness. Please see appendix for a sample of the EHI

AQ (Sutherland & Crewther, 2010; Bayliss et al., 2011; Freeth et al, 2013; Lundqvist & Linder; 2017; Baio et al., 2018). Therefore, in order to reap the most differences between groups, a score of 32 and above was set for the High AQ group.

The High AQ group consisted of twenty- five participants (10 females, 15 males, Mean age in years: 22.0 years old, SD = 1.4) and the average score of the High group on the AQ was 36.84 *(SD = 4.37).* The Low AQ group also consisted of twenty-five participants (12 females, 13 males, Mean age in years: 22.04, SD = 0.84*)* and the average score on the AQ was 18.56 *(SD = 5.31)*. Respondents were unaware of their scores and group allocation till after all experimental procedures were completed.

Informed consent was obtained from all participants. The experimental procedures were approved by the Faculty of Science Research Ethics committee, University of Nottingham Malaysia Campus.

2.2.2 Materials

a) Questionnaire measures:

Illusion Ownership Questionnaire- An adapted version of the acclimatization questionnaire (Newport et al., 2010) was used during the MIRAGE illusion investigation. These questions were chosen as they have been used previously in other investigations using the MIRAGE system (Newport & McKenzie, 2011; Bellan et al., 2015). This consisted of: (i) ownership statements which were used to assess the respondent's experience of limb ownership in each of the three conditions, (ii) somatosensory statements which were used as a measure of the amount of illusionary touch sensations reported, and (iii) non-somatosensory statements that were used as control questions. Table 2.1 shows the statements used during the study, all statements were presented in a random order, counterbalanced between each participant. Participants made verbal judgements on a 9-point numeric rating scale in which 1 indicated strongly disagree and 9 strongly agree.

Item Type	*Text (statement)*
Illusion Ownership	1. The hand no longer feels like my hand (Reverse scored)
	2. The hand belongs to me
Somatosensory Scores	1. I can feel a tingling sensation in my hand
	2. My hand feels like it has pins and needles
	3. I experience itching in my hand
	4. It feels like something is touching my hand
	5. I can feel an unpleasant sensation in my hand
Non-Somatosensory (control)	1. I can hear something unusual when I look at my hand
	2. My hand feels like it is floating in air
	3. My hand feels heavier than normal

Table 2.1 Statements used to measure limb ownership and somatosensory experience of respondents across all conditions.

b) *MIRAGE system*: MIRAGE multisensory illusion box was used to deliver all visual stimuli to the participants in the present study. MIRAGE is an augmented reality box that enables participants to view live video images of their own hands (with a delay of < 17 sec) in the same physical location as their real hands (Newport & Gilpin, 2011). This device enables us to modify the sensory information that your brain receives about the size, shape and movements of your hands, which helps in creating a discrepancy between what you feel (manipulation of the image of the hand) and what you know (higher- level cognitive processes) which ultimately gives rise to the illusion.

The visual stimuli used in the study consisted of live video images captured via the camera in the MIRAGE system which were presented in a manipulated or an un-manipulated version using customized software (Labview). Respondents viewed their right hand under three conditions; (i) veridical (baseline) condition in which no manipulation was applied to the hand (ii) darkened condition which was used a control for the experimental condition and a (iii) static (crawling skin) condition in which the appearance of the hand was manipulated to create a pixelated effect (see Figure 2.1). In the static condition, random pixels of the hand that moved were replaced by black pixels, creating a fuzzy/ grainy appearance on the hand. This was similar to the visual stimuli used by McKenzie and Newport's (2015) study in which the susceptibility of individuals with a tendency towards MUS traits was assessed using the crawling skin illusion (McKenzie & Newport, 2015).

Figure 2.1: The Veridical (A), Darkened (B) and Crawling (C) visual conditions.

2.2.3 Procedure

Participants received both written and verbal instructions about the task after which they were seated in front of the MIRAGE system and placed their right hand inside the system. A brief period of acclimatization was given (approximately 40 seconds), during which time they were allowed to move their hand within the MIRAGE system in order to familiarize themselves with the set up. A black bib was worn by participants throughout the procedure to block out the view of their arms, in order to block proprioceptive knowledge about the arm.

Participants viewed a video image of their right hand for three minutes in three different conditions (veridical, darkened and static) and a one-minute break was given between each condition during which participants were asked to take their hand out of the MIRAGE system in order to prevent any carry-over effects. The veridical (baseline) condition was conducted first for all participants as this was used as a reference by which performance in other conditions was compared against. This also ensured that the baseline condition was not contaminated by any carryover effects from the darkened and the static conditions. Following the veridical condition, all respondents were subjected to the darkened and crawling skin visual condition in a counter- balanced order.

During each of the conditions, participants viewed their stationary hand for a total of three minutes. After viewing their hand for three minutes, all participants were required to rate a series of statements related to hand ownership in different conditions, somatosensory experience and a few control statements (non- somatosensory statements) *(For the complete list of statements used, see table 2.1).* These statements were readout by the experimenter and the participants verbally rated each statement on a 1 to 9 rating scale (1 = strongly disagree, 9 = strongly agree). During the course of the experiment, participants were instructed to pay attention to their right hand, and received no feedback. The whole experimental session lasted for no longer than twenty- five minutes.

2.4. Results

Participants verbally scored each statement on a 1 to 9 rating scale, where 1 denoted strong disagreement and 9 were strongly agree. For each set of ratings, the data was analyzed using a 3 (Conditions: Veridical-control vs Darkened vs Crawling skin) x 2 (Groups: HighAQ vs LowAQ) ANOVA with conditions as the within – items factor and groups as the between-subjects factor. Unless otherwise stated, pairwise comparisons (Bonferroni- corrected) were used to assess the direction of main effects and t-tests were computed to test any significant interactions. Greenhouse-Geiser was used if sphericity was violated.

2.4.1. Non-Somatosensory Ratings

A 3 (Conditions: Veridical Vs Darkened Vs Crawling) x 2 (Groups: High AQ Vs Low AQ) Repeated measures ANOVA was conducted to measure the differences between the non-somatosensory statements. This revealed no significant main effect of condition, $F (2, 48) = .116, p = .890 (\eta^2 = .002)$ or an interaction between groups and conditions, $F (2, 48) = .328, p = .720 (\eta^2 = .007)$. For the means obtained by both the groups in each condition, please see appendix 4. a. As there were no differences found in the non- somatosensory statements, this indicates that participants were attentive during rating the statements (see Fig 2.2).

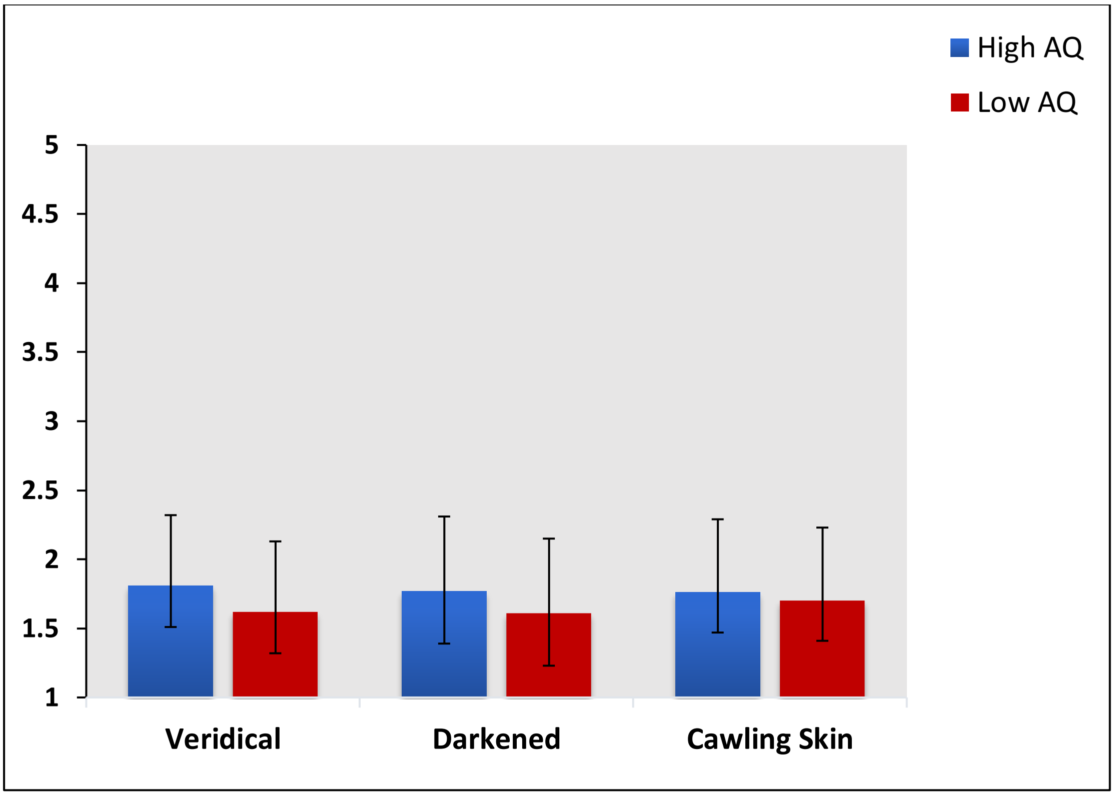


Figure 2.2. Mean non- somatosensory scores given by the High AQ (blue) and Low AQ (red) across all conditions. As displayed, no significant differences were found between the group's ratings.

2.4.2. Ownership Ratings

In order to examine the difference between ownership given to the video hand in all three conditions, ratings to the ownership statements *"the hand belongs to me"* and *"the hand no longer feels like my own hand" (reverse scored)* were averaged to obtain a mean ownership score. A 3 x 2 Repeated Measures ANOVA revealed a significant main effect of condition, *F*

(2, 48) = 59.04, p < .001 (η^2 = .552), indicating participants differed in terms of ownership over the video hand in all three conditions (see figure 2.3). Pairwise comparisons (Bonferroni-corrected) revealed that respondents gave the highest amount of ownership to the digitally presented hand in the veridical-baseline condition *(Mean = 7.49, SD = .169),* followed by the darkened condition *(Mean = 6.70, SD = .170)* and the least amount of ownership to the video hand in the crawling skin conditions (*Mean = 4.96, SD = .198)*. There was also a significant main effect of group, with *F (2, 48) = 10.82, p = .002 (η^2 = .184),* indicating that the high AQ group consistently had higher ownership scores across all conditions compared to the low AQ group.

More importantly, there was a significant interaction between group and condition, *F (2, 48) = 4.79, p = .01 (η^2 = .091)*. Three Post- hoc independent samples t- tests (Bonferroni-corrected) were conducted, no significant differences in ownership scores were found between the ratings given by the respondents in the baseline condition, *t (1, 49) = .423, p = .519*, (*η^2 = .003)* suggesting that in the veridical-baseline condition, respondents in the high AQ group (*Mean = 7.60, SD = 0.28)* and low AQ group *(Mean = 7.38, SD = .97)* gave similar amounts of ownership over the digitally presented hand and similarly, in the darkened condition, there were no significant differences in the mean ownership ratings, *t (1, 48) = 1.67, p = .203, η^2 = .005)*. However, there was a significant difference in ownership ratings in the crawling skin condition, *t (1, 48) = 16.35, p < .001*, (*η^2 = .332)* suggesting that individuals in the High AQ group gave higher ownership to the pixelated hand *(Mean = 5.76, SD = 1.38),* compared to respondents in the Low AQ group *(Mean = 4.16, SD = 1.42).*

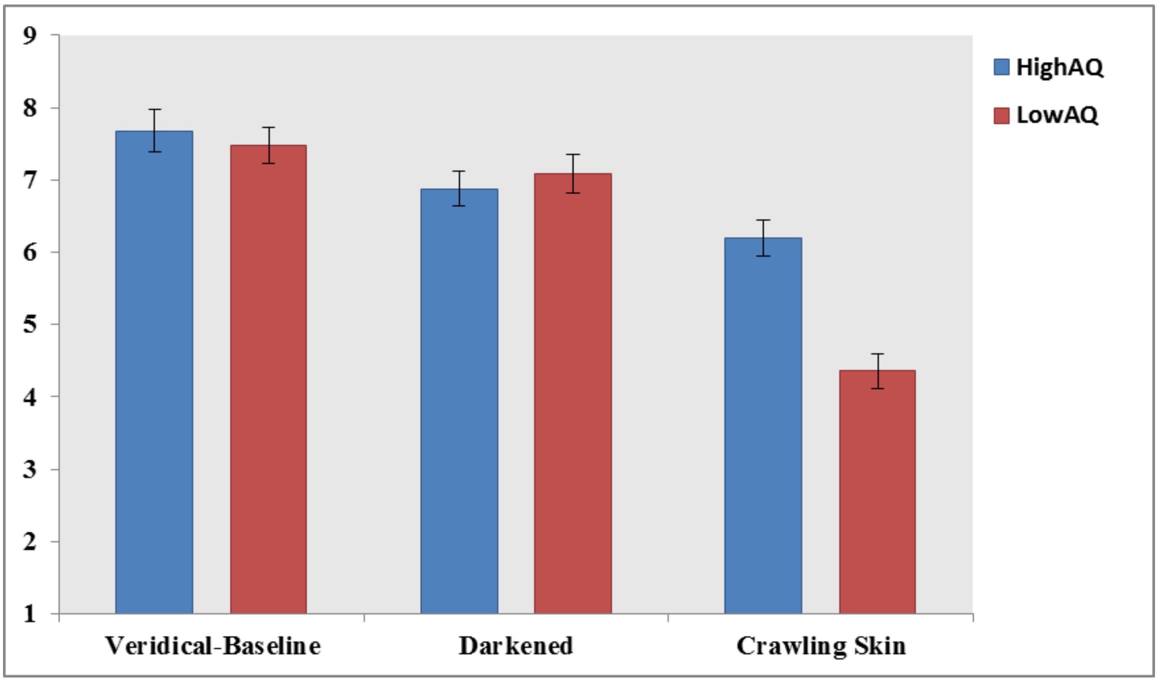


Fig. 2.3 Mean ownership scores given by respondents in the High AQ (blue) and Low AQ (red) groups across all three conditions. Over all, participants in the High AQ group gave higher ownership ratings across all conditions. No differences were found in the veridical-baseline or darkened conditions, whereas, ownership scores were significantly reduced for the Low AQ group in the static condition.

2.4.3. Somatosensory Ratings

To examine visually induced somatic sensations the scores for the statements relating to somatosensory sensations (e.g. statements related to pin and needles sensation, tingling, throbbing sensation and unpleasant feeling in the hand) were averaged to obtain a mean "somatosensory score" for each participant. These statements were used only because they relate to somatosensory sensations. A 3 x 2 repeated ANOVA revealed a significant main effect of condition, $F(2, 48) = 125.33, p < .001$ ($\eta^2 = .723$) (see figure 2.4). Pairwise comparisons (Bonferroni- corrected) revealed that respondents, regardless of the condition, reported the least amount of somatosensory sensations in the veridical-baseline condition *(Mean = 1.84, SD = .10)*, followed by the darkened condition *(Mean = 2.29, SD = .14)* and the highest number of somatosensory sensations were reported in the crawling skin condition *(Mean = 4.01, SD = .176)*. There was also a main effect of group, $F(2, 48) = 54.72, p < .001$ ($\eta^2 = .533$), suggesting that respondents in the low AQ group had consistently higher somatosensory scores across all conditions, compared to the high AQ group.

A significant interaction between groups and conditions was found, $F(2, 48) = 94.43, p < .001$ ($\eta^2 = .663$). In order to explore this interaction further t- tests (Bonferroni- corrected) were computed. No significant differences were found in the somatosensory scores between the high AQ (Mean: 1.81, SD = .849) and low AQ (Mean: 1.88, SD = .55) groups during the baseline (veridical) condition, $t(1, 48) = -3.12, p = 0.63$, ($\eta^2 = -.447$). A significant difference in the number of somatosensory ratings was found in the darkened condition $t(1, 48) = 1.23, p = .001$, ($\eta^2 = .039$), where individuals scoring lower on the AQ reported higher number of somatosensory sensations *(Mean: 2.77, SD = 1.10)* compared to average ratings given by respondents in the high AQ group *(Mean: 1.80, SD = .99)*. We also a found a significant difference in the average somatosensory scores between the two groups in the crawling skin condition, $t(1, 48) = 2.69, p < .001$, ($\eta^2 = .070$) , where respondents in the low AQ group reported feeling more visually induced somatosensory sensations *(Mean: 6.07, SD = 1.14)* compared to respondents in the high AQ group who reported feeling lesser sensations *(Mean: 2.08, SD = 1.34)*.

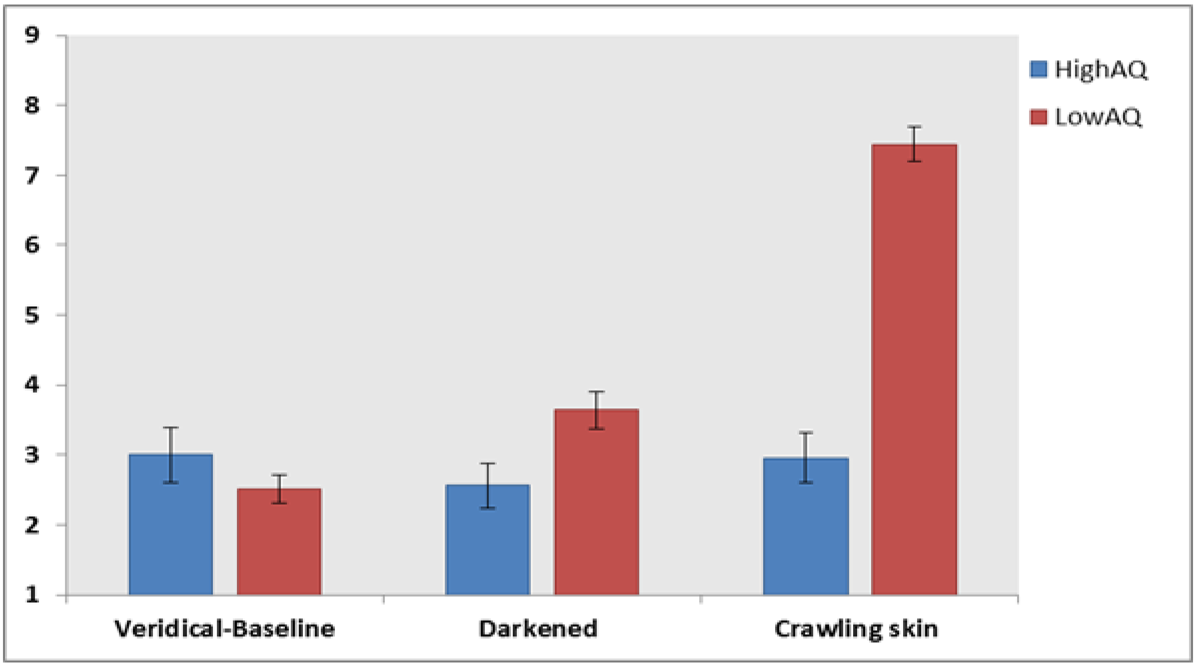


Figure 2.4: Ratings for somatosensory experience reported by participants in the High (blue) and Low (red) AQ groups across all conditions. Note the high somatosensation reported in the Crawling condition for the Low AQ group.

2.5. Discussion

We investigated whether individuals of typical development who exhibit high autism tendencies would be more or less susceptible to a visual illusion which evokes feelings of tactile sensations on the skin when none are presented. As the static hand illusion creates visually induced tactile sensations without any tactile input, it was expected that individuals with high autism traits would be less susceptible towards this illusion. Previous research indicates that individuals with high autism traits and those with autism are more sensory- driven when integrating and interpreting sensory information in regards to their own bodily self. Therefore, participants viewed a real time video image of their own right hand, or a digitally altered live view of their right hand with either darker luminance or a pixelated effect (static) on it. Participant's subjective reports of somatosensory sensations and hand ownership were compared in individuals who either reported high or low number of autistic traits as assessed by the AQ (Baron-Cohen et al, 2001). The results suggest that individuals reporting lower numbers of autistic traits were more influenced by the subjective effects of the static hand illusion, this is reflected in the significantly higher number of visually induced somatic sensations reported in the darkened and static condition compared to those with higher autism traits.

Respondents in the high and low AQ groups reported similar amounts of ownership to the video hand in the veridical-baseline condition and the darkened condition. However, during the static condition, participants in the high AQ group reported higher ownership over the static hand compared to the low AQ scorers. This difference in ownership of the hand in the static condition could be attributed to the disruption the visual manipulation of the hand causes which contradicts participant's existing knowledge about their own hand resulting in lower ownership of their own hand. However, in light with the current findings, this does not seem to be the case as the high AQ group gave ownership to the static hand suggesting a greater reliance on their cognitive knowledge regarding their own hand or a lesser influence of the incoming sensory information. This is a novel finding and is not consistent with that of McKenzie and Newport's (2015) study as their results demonstrated that individuals with higher SDQ- 20 scores reported lower feelings of ownership during the static condition, therefore, this can be attributed to the differences in sensory profiles of those with autism traits and MUS traits.

In terms of the number of visually induced somatosensory sensations, the static hand illusion did indeed increase the reports of visually induced somatosensations compared to the veridical-baseline and darkened conditions. This effect was achieved through a purely visual manipulation. During the darkened condition there was a slight increase in the reports of somatosensory sensations in the low AQ group, but not in the high AQ group. Compared to the veridical-baseline condition, respondents in the low AQ group reported feeling significantly higher number of illusionary sensations felt compared to high AQ scorers during the static condition. In illusory terms, this could mean that those with lesser number of autism traits are processing information that is coming in, i.e. in this case the visual manipulation, whereas, this is not the case for those with high autism traits as they are not processing this incoming visual input but they seem to be driven by cognitions, where they are not integrating the sensory information being presented.

McKenzie & Newport (2015) found that participants reporting more visually induced somatosensory sensations felt less ownership over their digitally presented hands. This is consistent with the findings of the current study, as individuals who reported less ownership over the digitally presented hands reported feeling more visually induced somatic sensations during the static condition. However, this pattern of results was only present for the low AQ group but not the high AQ group. Individuals scoring lower on the AQ reported higher number of visually induced somatosensation, which resulted in loss of ownership over the digitally presented hand.

In comparison to McKenzie and Newport's (2015) study, the pattern of differences could be due to the two populations studied. McKenzie and Newport (2015) tested individuals with MUS tendencies whereas the current investigation compared the performance of individuals of typical development exhibiting high or low autistic traits. In their study, individuals with higher SDQ scores reported higher somatic sensations across all visual conditions, even when baseline scores were factored out. This was interpreted in terms of having an elevated sensory baseline in which individuals misinterpret "sensory noise" as a 'signal', irrespective of current sensory input. However, this is not the case for the outcome of the current study, where the results demonstrated that individuals with lower number of autistic tendencies reported higher somatic sensations. At an illusory level, the pixelated effect over the participants right limb is creating a mismatch between what the participant is viewing and what they already know. Therefore, the three minutes during which this happens is sufficient for the typically developing low AQ scorers who are susceptible to this mismatch between their incoming visual information and the existing knowledge about their limb. Therefore, the optimal manner in which perception works, is active in those with low scores, where the visual information (sensory information) is over ridding one's knowledge about their own limb. However, this is not the case for those with high autism traits, as they retained ownership over their hand during the pixelated (static condition), however, they reported significantly lesser number of sensations or displayed a reduced effect of the visual manipulation, indicating a stronger reliance on one's existing knowledge rather than being affected by the visual information.

The reliance on top- down and bottom- up information has previously been tested in individuals with autism traits (Palmer et al, 2013) and those with a clinical diagnosis of autism (Paton et al, 2012) using the rubber hand illusion. Findings from Palmer et al's (2013) investigation suggested that individuals with high autistic tendencies demonstrated an overall reduced effect of the illusion on perceived arm position compared to those with fewer autistic traits. However, individuals with high autism traits displayed enhanced proprioceptive performance. These findings were interpreted as reflecting an increase in the reliance on sensory (proprioceptive) input, i.e. selecting one particular sensory source rather than integrating several sources, at the expense of the more overall context of the illusion. These results are consistent with other research measuring sensory performance in autism in measuring visuo- tactile integration (Makin et al., 2008; Paton et al, 2012; Cascio et al, 2012). In comparison to the results of current study, individuals with high autism traits displayed a pattern where they make judgements regarding their own hands in a virtual environment based on their existing knowledge. This pattern of top- down reliance in those with higher autism traits is a novel finding, but it could be suggested that individuals with high autism traits, similar to those with autism, make inferences about visual information based on their existing knowledge rather than integrating co-current sensory information (Dakin and Frith, 2005), which could explain some of the deficits associated with social interaction in autism.

The results suggest that individuals with a higher number of autistic tendencies rely more on their existing knowledge regarding their limb when interpreting incoming visual information. It is not possible to make any strong claims regarding performance as the pattern of visual processing might differ in those with a clinical diagnosis of autism as sensory atypicalities are more intense compared to those with autism tendencies. However, this study provides us with baseline differences in visual processing and inferences regarding performance of individuals with autism can be made to establish a direction for future investigation. In order to examine these differences further, the next chapter would examine visual processing in individuals with a clinical diagnosis of high- functioning autism and typically developing individuals. If a similar pattern of results if found in the autistic population, this could strengthen the claim in this type of illusion, participants who are less susceptible because they rely more on their pre- existing knowledge rather than integrating bottom- up sensory information when interpreting the incoming visual information or this could only be present when unimodal illusions are presented to such a population.

Chapter Three

Experiment two

Crawling Skin Illusion Susceptibility in Individuals with High- functioning Autism and Typically Developing Adults

3.1 Introduction

Atypical reactions to sensory stimuli are very common in individuals with autism, where majority of studies have reported a prevalence of above 90 % for both children and adults with autism (Leekam et al., 2007). These atypical reactions manifest themselves as hyper-reactivity or hypo-reactivity to sensory input, or an unusual interest in certain sensory aspects of the environment, such that these sensory profiles are now explicitly included as a symptom subdomain in the latest version of the Diagnostic and Statistical Manual of Mental Disorders fifth edition (DSM- 5) criteria for autism (American Psychiatric Association, 2013b). Furthermore, these sensory variations are seen in more than a single sensory domain, extending to multiple sensory modalities (O'Neill & Jones, 1997; Dawson & Watling, 2000; Rogers et al., 2003; Wing & Potter, 2002; Baranek et al., 2006)

Emerging evidence strongly supports the idea that a typical multisensory integration in the autistic population is responsible for the sensory atypicalities often seen in those with autism, whereby, some studies report lower susceptibility to illusions due to higher reliance on top- down information and others argue that individuals with autism tend to rely more on a singular sensory input rather than combining multiple sources (Cascio et al., 2012; Greenfield et al., 2015; Stevenson et al., 2016). Multisensory integration in the autistic population has been investigated using various illusionary paradigms, extending over multiple sensory domains, such as audiovisual processing has been investigated using the " flash beep" illusion (Van Der Smagt et al., 2007) where individuals with autism have shown lower susceptibility compared to those of typical development. Similarly, the McGurk effect has been employed in the autistic population, where individuals on the spectrum have shown lower susceptibility (Gelder et al., 1991; Massaro & Bosseler, 2003; Stevenson et al., 2014), indicating a lower influence of visual information.

In the current investigation, I will be replicating the previous study (Chapter 2) in individuals with high- functioning autism (HfA) and an age and IQ matched comparison group of typically developing adults. Both groups were subjected to the crawling skin illusion during which participants viewed their right hand under three different visual conditions which consisted of a baseline condition, an experimental (static skin) condition during which the video image of the hand was manipulated to make it look pixelated and a darkened condition which was used as a control for the experimental condition. Past research that has used visual illusions in individuals with autism has presented us with an unclear picture, whereby, most studies have tried to understand perceptual processing in autism using 2- dimensional static stimuli, such as the Müller- lyer illusion (Hoy et al., 2004; Chouinard et al., 2013) or the Shepard's illusion (Michel et al., 2010). Even though at the core of its being, these are visual illusions and have contributed a lot towards our knowledge regarding visual perception in autism, however, they have been questioned regarding their methodologies and procedures. Furthermore, the rubber hand illusion (Paton et al., 2012) is a more dynamic and widely used illusion. The illusion consists of two parts where the success during the first part of the illusion facilitates the second part. As the current study deals with a visual illusion, I will be focusing more on the first part of the RHI which mainly deals with individuals giving ownership towards a fake rubber hand, whereby, in the current scenario they will be viewing their own hand but a digital version.

It has been suggested that due to the rigid thinking style of people with autism, it reduces the possibility of them being susceptible towards a fake rubber hand. This is a common finding and several studies have argued that a higher dependence on their own existing knowledge regarding their own limb limits them from giving ownership towards the rubber hand (Cascio et al., 2014; Cascio et al., 2015; Palmer et al., 2013; Paton et al., 2012), resulting in reduced susceptibility. Furthermore, in the previous investigation (chapter 2, experiment 1), we found that individuals with high autism traits were not influenced by the visual manipulation of the hand as they reported lesser number of somatosensations compared to those with low autism traits. Therefore, in order to further examine this idea, I will be replicating the previous study and present the crawling skin illusion (Newport & McKenzie, 2015) to a group of high- functioning adults and their typically developing counterparts. I hypothesize that due to the high visual and spatial similarities between the participants own hand and that viewed through the MIRAGE screen, both groups should report higher ownership in all conditions, especially the autistic group in the experimental condition. We predict a drop-in ownership for the control group during the experimental condition (crawling skin) as the visual information being manipulated would be sufficient to disown their own limb, which would result in higher somatosensataion scores. This is due to the weightage given to visual information which over- rides their existing knowledge of their hand. Based on past research that indicates that individuals with HfA show a bias for local elements over the global aspects of a stimuli (Chouinard et al., 2013; Hoy et al., 2004) and the fact that visual integration in autism is atypical compared to TD population; the HfA group will report lower somatosensory scores. This would be because of higher dependence on their own existing knowledge regarding their own hand while ignoring the co-current visual influence.

3.2. Method

3.2.1 Design

A 3 x 2 mixed design was used in the current investigation, in which the three visual conditions under which the participants viewed their right hand (Veridical-Baseline, Darkened and Crawling skin conditions) were the within- item factors and group (HfA and typically developing adults) was the between group factor. The dependent measures in the current investigation were the respondents' subjective ratings during each of the visual conditions.

3.2.1.Participants

Given the large variation in cognitive impairments seen across autism spectrum disorders, I choose to narrow the experimental group to individuals with a clinical diagnosis of high- functioning autism (HfA) (see Chapter 1 for a fuller description of HfA). A total of thirty participants (see table 3.1 for participant characteristics) were recruited and consisted of fifteen right handed adults (8 males and 7 females) with high functioning autism (HfA) aged between eighteen to twenty-eight years of age (Mean age = 22.2 years, SD = 2.62) and a comparison group of fifteen *(9 females and 6 males)* age and IQ matched typically developing adults (Mean age = 22.0 years, SD = 2.91). Adults with HfA were recruited from the autism research group's database of local families that had previously taken part in autism research at the University of Nottingham, and also through a research advertisement that was placed at the wellbeing and support office at the University of Nottingham. The Nottingham autism research data base is a compilation of individuals with high- functioning autism who have been recruited by researchers in the past who have given consent to be contacted to take part in any on-going experiments at the university. This data base includes both children and adults. Comparisons group participants were university students.

All participants in the HfA group held a clinical diagnosis of autistic disorder or high functioning autism obtained from a clinician based on the DSM- 5 criteria. In order to reconfirm their diagnosis, the Autism diagnostic and observational Schedule second edition (ADOS- II)[8] was conducted to obtain their ADOS scores for the clinical group (check table 3.1 for mean ADOS- II Social interaction and communication scores total). The status of the clinical group as "high- functioning" was reconfirmed by their performance on a standardized cognitive assessment, Wechsler Adult Intelligence Scale – fourth edition (WAIS-IV) (see table 2.1 for the groups full scale Intelligence scores). Both the ADOS – II and the WAIS- IV tests were conducted by myself. The sessions were recorded and a group of individuals with similar training rated the sessions anonymously in order to provide a reliable and consistent scoring for both the tests. Groups were matched on the overall Intelligence scores, where there was no significant difference found between the full-scale IQ of the HfA and comparison group, t (2, 28) = - .168, p = .868. Furthermore, both groups filled out the Autism Spectrum Quotient (AQ)

[8] The Autism Diagnostic Observation Schedule, Second Edition (ADOS-II) is a behavioral test of autism that has been used in clinical samples and research settings. It is considered as a "gold-standard" test in front of the rest.

(Baron- Cohen et al., 2001). The HfA participants and the control in the following chapters (chapter 5 and chapter 7) were the same group of people.

All experimental procedures were approved by the University of Nottingham, School of Psychology Ethics committee. As all participants that took part in the current investigation were adults, consent was obtained prior to taking part in any of the experimental procedures.

Group (Sample Size)	**Statistic**	**Age (Years)**	**Autistic Quotient (AQ)**	**ADOS-II Total (communication + social interaction)**	**Verbal IQ (VIQ)**	**Performance IQ (PIQ)**	**Full-Scale IQ (FSIQ)**
HfA	Mean	22.2	40.7	10.87	101.73	110.87	106.73
(15)	SD	2.62	4.35	2.92	17.49	14.74	15.08
	Range	*18 - 27*	*32 – 46*	*7 - 17*	*66 -127*	*72 – 125*	*75 - 125*
Controls	Mean	22.0	13.5	N/A	101.67	112.47	107.53
(15)	SD	2.91	6.83		12.90	12.34	10.7
	Range	*18 - 28*	*3 – 27*		*87 - 128*	*90 – 127*	*87 - 123*

Table 3.1 Displays the participant characteristics for the High- functioning autism group and typically developing control group

3.2.2Materials

a) Questionnaire Measures

Similar to the previous chapter (Chapter 2) the ownership and illusion strength questionnaire was used during the MIRAGE investigation. This consisted of (i) ownership questions, assessing the amount of ownership the respondents felt over their hand during all three visual conditions, (ii) Somatosensory questions that were used to measure the number of somatosensory sensations reported by the respondents and (iii) non- somatosensory questions that were used as control questions (see table 3.2 for the statements used for the MIRAGE investigation). Respondents verbally rated these statements on a 7.0 rating scale, where -3 denoted strong disagreement, 0 referred to neither agree or disagree and 3 denoted strong agreements with the statements. In the previous chapter, I used a 9.0 rating scale with all positive values negating both agreement and disagreement. However, to make it less ambiguous for participants, a negative to positive scale was used in the current study, where negative values referred to disagreement and positive ones were related to agreement. This was done because individuals with autism are extremely context- dependent; therefore, negative values denoted disagreement and positive values referred to agreement. Furthermore, the changes in the rating scale from all positive to positive to negative values was made to ensure if participants were less susceptible to the illusion, they could associate with a negative value. Using a rating scale with both negative to positive values has been shown to be more effective in recording responses in previous studies (Regehr et al., 1988), especially when testing populations with a deficit such as ASD (Chlebowski et al., 2010; Crawford & Henry, 2004).

Item Type	*Text (statement)*
Illusion Ownership	The hand no longer feels like my hand (Reverse scored)
	The video hand belongs to me
Somatosensory Scores	I can feel a tingling sensation in my hand
	My hand feels like it has pins and needles
	I experience itching in my hand
	It feels like something is touching my hand I can feel an unpleasant sensation in my hand
Non-Somatosensory (control)	I can hear something unusual when I look at my hand
	My hand feels like it is floating in air
	My hand feels heavier than normal

Table 3.2 Statements used to measure limb ownership and somatosensory experience of respondents across all conditions during the MIRAGE investigation

MIRAGE Illusions

The MIRAGE multisensory illusion system was used present participants with the visual stimuli in the current investigation. The visual stimuli were presented over live video images of participant's right hand in either a manipulated or un-manipulated version using custom software (LabView). This consisted of three conditions: (i) Veridical-Baseline condition during which respondents viewed their right hand without any manipulation, (ii) Crawling skin condition which was the experimental condition during which the video image of the participants' right hand was manipulated to create a pixelated effect and (iii) a darkened condition in which the overall luminance of the hand was matched to that of the static condition, but without the pixelated effect. This was used as a control condition for the experimental condition (Static Hand). Participants viewed their hands in each of the conditions for a total of three minutes after which they responded to the ownership, somatosensory and control statements. A break for two minutes was given between each condition during which participants were required to take their right hand out of the MIRAGE system in order to reset sensations.

Figure 3.1: The Veridical (A), Darkened (B) and Crawling (C) visual conditions

3.2.3 Procedure

Written and verbal instructions detailing the task were presented to the participants and they were made aware of the rating scale that was printed in A4 size and kept in view of the participant. They were informed that during the course of the experiment, they will be required to verbally rate statements regarding their experience. Following this, participants were seated in front of the MIRAGE system and were instructed to place their right hand inside the opening of the MIRAGE system. A black bib was worn by the participants throughout the experimental task to block the view of the arms during the MIRAGE investigation.

A brief acclimatization period was given (approximately 60 seconds), during which time they were allowed to move their hand within the MIRAGE in order to familiarize themselves with the experimental set up. Following this brief period, all participants were presented with the Veridical-baseline condition first, during which they viewed live video image of their own right hand without any manipulation for a total of three minutes after which they were asked to verbally rate questions related to hand ownership, somatosensory experience and a few control statements. Once the statements were rated by the participants, they were asked to take their hand out of the system for one minute before carrying on with the rest of the task. All participants were presented with the veridical-baseline condition first in order to ensure that there was no carry- over effects from the other settings. Following the veridical- baseline condition, respondents were presented with the darkened and the crawling skin conditions in a counter- balanced order.

During each of the conditions, the participants were simply required to observe their stationary hand for a total of three minutes after which they were required to rate illusionary ownership and sensation statements. Statements were counter- balanced between conditions and participants. Respondent's verbally rated each statement on a 7.0 rating scale, where -3 indicated strong disagreement and 3 indicated strong agreement[9]. Throughout the duration of the task participants were informed to pay attention towards their hand; the entire session lasted for no more than twenty-five minutes.

3.3 Results

[9] The rating scale for this investigation was modified from a 9.0 scale (experiment 1) to a -3 to +3 scale for the ratings. In order to reduce cognitive load for the autistic participants, negative ratings were associated with a reduced experience of the illusion, whereas, positive ratings indicate the experience of the illusion.

Participants' subjective ratings in each of the visual conditions were computed as the dependent variable for the current study. Respondents verbally scored ownership, somatosensory and control statements on a -3 to 3 Likert scale, where -3 denoted strong disagreement and 3 referred to strong agreement. For each set of ratings, the data was analyzed using a 3 *(Conditions: Veridical-Normal Vs Darkened Vs Crawling skin)* x 2 *(Groups: HfA vs Control)* ANOVA with conditions as the within- items factor and groups as the between-subjects factor. Pairwise comparisons (Bonferroni- corrected) were used to assess any main effects and t- tests were computed to test any significant interactions.

Non- Somatosensory (control) Statements

A 3 x 2 Repeated measures ANOVA revealed no significant main effect of conditions for the control statement, $F(2, 28) = 2.09$ $p = .134$ ($\eta^2 = .013$), or significant interaction, $F(2, 28) = .155$, $p = .134$ ($\eta^2 = .002$). This indicates that participants were attentive while ratings ownership and somatosensory statements across all visual conditions (Figure 3.2). (Please see Appendix 4.b. for the average scores)

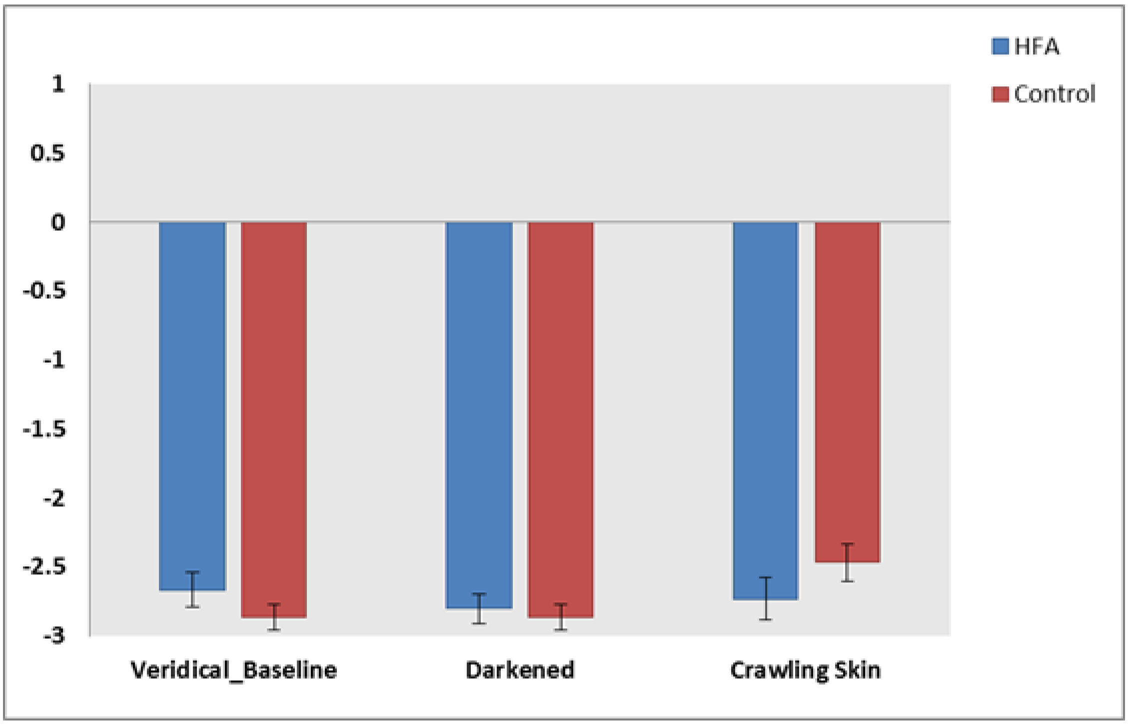


Figure 3.2 Non- somatosensory (control) statement ratings given by the HfA (blue bars) and control group (red bars) across all visual conditions.

3.3.1 Ownership Ratings

In order to examine the differences in ownership felt over the hand in all three visual conditions, ratings to the ownership statement "the hand belongs to me" were computed as a mean ownership score for each participant. A 3 x 2 ANOVA revealed a significant main effect of condition, $F\ (2,\ 28) = 30.74,\ p < .001$ ($\eta^2 = .523$), indicating differences in ownership ratings. Pairwise comparisons (Bonferroni- corrected) revealed no significant difference in ownership ratings veridical-baseline and darkened conditions, $p = .272$, ($\eta^2 = 0.361$), indicating respondents felt similar amounts of ownership over their hand in the veridical-baseline *(Mean = 2.167, SD = .139)* and darkened conditions *(Mean = 1.97, SD = .124)*. A significant difference in ownership ratings was found between veridical-baseline and static hand conditions, $p < .001$, (η^2 *= .995)*, suggesting that respondents felt higher ownership over the hand during veridical-baseline condition *(Mean = 2.17, SD = .139)* compared to the crawling skin condition *(Mean = .533, SD = .221)*. There was also a significant difference in ownership ratings between darkened and static conditions, $p < .001$, (η^2 *= .806)*, indicating that respondents gave higher ownership ratings during the darkened condition *(Mean = 1.97, SD = .124)* compared to the crawling skin condition *(Mean = .533, SD = .221).* A significant effect of group was also found, $F (2, 28) = 26.92, p < .001$ (η^2 *= .490),* indicating that during the baseline condition, HfA group had higher ownership scores *(Mean= 2.20, SD= .676)* compared to the control group *(Mean = 2.13, SD = .833)*. During the darkened condition the HfA group had higher ownership scores *(Mean = 2.00, SD .654)* compared to the control group *(Mean = 1.93, SD = .703)*. Similarly, the HfA group had higher ownership ratings during the static hand condition *(Mean = 2.06, SD = .703)* compared to the control group *(Mean = - 1.00, SD = 1.55)*.

There was also a significant interaction between conditions and groups, $F (2, 28) = 29.05, p < .001$ (η^2 *= .509)*. Three Post- hoc independent samples t- tests (Bonferroni-corrected) were computed to assess the interaction. There were no differences in ownership ratings found between groups for the veridical-baseline condition, $t (2, 28) = .241, p = .812$, (η^2 *= -.134)*, indicating that during the veridical-baseline condition individuals with high-functioning autism *(Mean = 2.20, SD = .676)* and the typically developing comparison group *(Mean = 2.13, SD = .834)* felt similar amounts of ownership over the hand. Similarly, no significant differences in ownership ratings was found between groups during the darkened condition, $t (2, 28) = .790, p = .790$, (η^2 *= - .184)*, suggesting that the HFA group *(Mean = 2.00, SD = .655)* and comparison group *(Mean = 1.93, SD = .704)* felt similar amounts of ownership over the video hand in the darkened condition. However, there was a significant difference in ownership ratings between groups during the experimental (crawling skin) condition, $t\ (2, 28) = 6.95, p < .001, (\eta^2 = .638)$, indicating that respondents in the HfA group *(Mean = 2.07, SD = .703*) felt higher ownership over the video hand compared to those in comparison group *(Mean = -1.00, SD = -1.56)* (Figure 3.3)

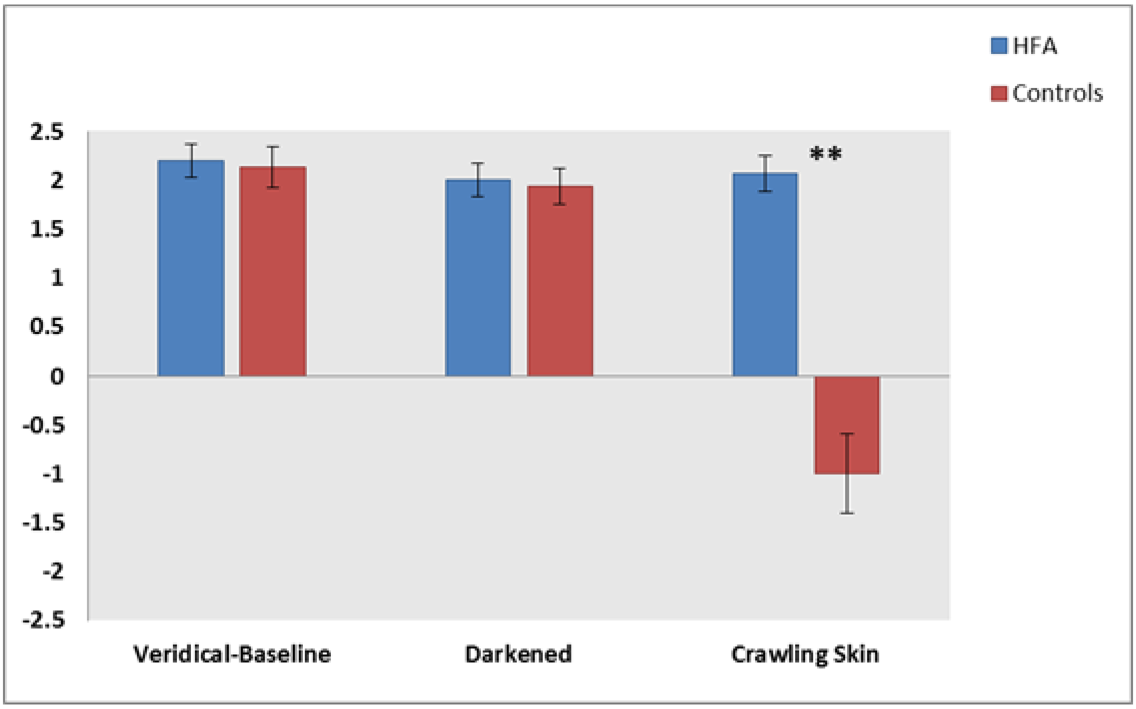


Figure 3.3 Graphical representation for the ownership ratings given by the HfA (blue bars) and control group (red bars) across all visual conditions during the MIRAGE investigation. No statistically significant differences in means were found between groups during the veridical- baseline and darkened conditions. However, the respondents in the control group had significantly lower ownership ratings compared to HfA group during the crawling skin condition.

Somatosensory Ratings

Highest somatosensory ratings given by participants for statements related to "*tingling sensation in hand, unpleasant sensation, pins and needles and itching in my hand"* was used as the somatosensory score for each participant. A 3 x 2 ANOVA revealed a significant main effect of condition, *F (2, 28) = 104.6, p < .001* (η^2 *= .789)*, suggesting differences in somatosensory scores. Pairwise comparisons (Bonferroni- corrected) reveled a significant difference in somatosensory ratings between the veridical-baseline and darkened conditions, *p < .001,* (η^2 *= - .500),* indicating that respondents had the lowest somatosensory ratings in the veridical-baseline condition *(Mean = - 2.70, SD = .085)* compared to darkened condition *(Mean = - 1.73, SD = .207)*. A significant difference in somatosensory ratings was also found between veridical- baseline and static condition, *p < .001,* (η^2 *= - .971)*, indicating that respondents reported feeling more somatosensations during the static condition *(Mean = .100, SD = .078)* compared to veridical- baseline condition *(Mean = - 2.70, SD = .085).* There was also a significant difference in somatosensory ratings between the darkened and static conditions, *p < .001,* (η^2 *= - .712),* where respondents had higher somatosensory ratings during the static condition *(Mean = .100, SD = .078)* compared to the darkened condition *(Mean = - 1.73, SD = .207).* A significant effect of group was also found, *F (2, 28) = 260.61, p < .001* (η^2 *= .903)*, indicating that the HfA group *(Mean = - 2.60, SD = .507)* reported lesser number of somatosensations during the baseline condition compared to the control group *(Mean = 2.80, SD = .414)*. For the darkened condition the HfA group reported feeling lesser somatosensations *(Mean = - 2.73, SD = .457)* compared to the control group *(Mean = - .733, SD = 1.55).* For the static hand condition, the HfA group *(Mean = -2.66, SD = .487)* compared to the control group *(Mean = 2.87, SD = .352)*.

More importantly, there was also a significant interaction found between conditions and groups, *F (2, 28) = 108.2, p < .001* (η^2 = .794), indicating differences in somatosensory ratings between groups and across conditions. Three Post Hoc independent samples t- tests (Bonferroni-corrected) were computed to assess the interaction. There was no significant difference in somatosensory ratings between groups in the veridical-baseline condition, *t (2,28) = 1.183, p = .247,* (η^2 *= - .027)*, indicating that the HfA group *(Mean = -2.60, SD = .507)* and the comparison group *(Mean = -2.80, SD = .414)* strongly disagreed with the statements measuring somatosensory sensations during the baseline-veridical condition. There was a significant difference in somatosensory ratings between groups in the darkened condition, *t (2, 28) = -4.84, p < .001,* (η^2 *= - .268)*, indicating that respondents in the HFA group *(Mean = -2.73, SD = .457)* had higher disagreement ratings in the darkened condition compared to those in the comparison group *(Mean = -.733, SD = 1.53).* There was also a significant difference in somatosensory ratings between groups during the static condition, *t (2, 28) = -35.62, p < .001,* (η^2 *= - .968)*, indicating that respondents in the comparison group *(Mean = 2.87, SD = .358)* had higher somatosensory ratings compared to the HFA group *(Mean = - 2.67, SD = .352),* suggesting that the comparison group reported feeling higher number of somatosensory sensations during the static hand condition (Figure 3.4).

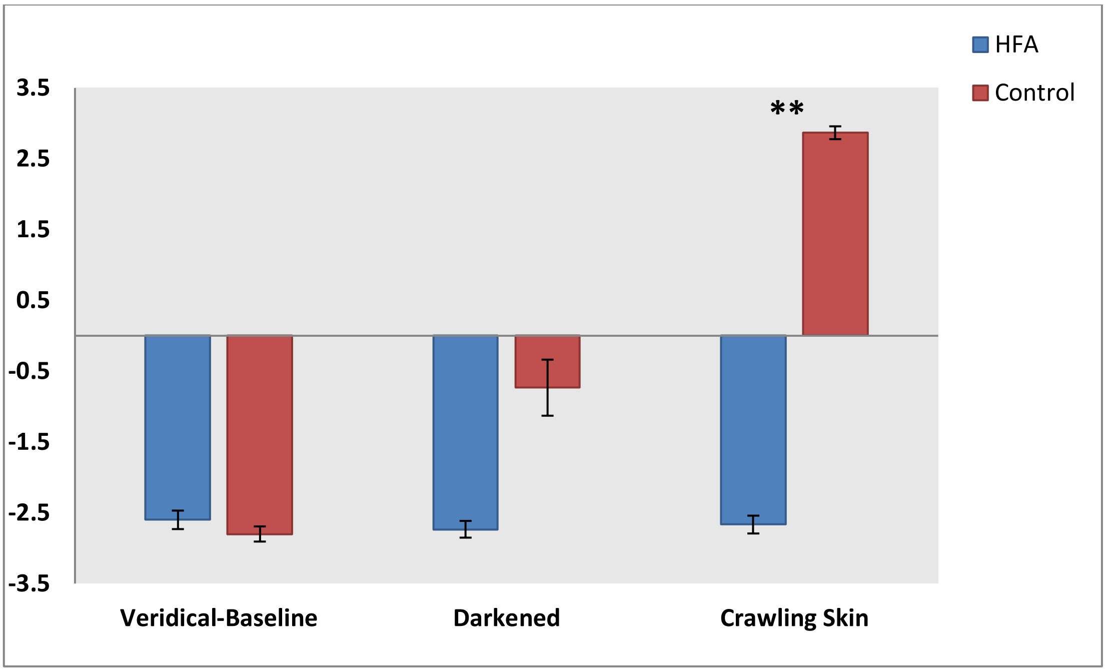


Figure 3.4 Somatosensory ratings given by the HfA (blue bars) and control group (red bars) across all visual conditions. There were no statistically significant differences in means between groups during the veridical-baseline condition. However, a significant difference in ownership ratings was found for the darkened and static conditions.

3.4. Discussion

The present study investigated the influence of visual information on top- down contextual knowledge about an individual's right hand in those with high- functioning autism (HfA) and an IQ matched comparison group of typically developing adults. Both the groups were subjected to the crawling skin illusion during which they viewed their right hand in a manipulated or un-manipulated version through the use of the MIRAGE mediated reality system (Newport & Gilpin, 2011). The results of the study indicated that the HfA group was less susceptible to the illusion, indicating a reduced effect of visual information in perceiving illusory somatosensations. However, individuals with HfA retained ownership throughout all the visual conditions. This was one of the predictions made for the current study and this provides us with further support for how atypical visual processing in autism could be due to either a higher dependence over one's own cognitive knowledge or due to failure to integrate co- current sensory information or bottom- up visual information.

The results showed that both groups reported feeling similar amounts of ownership over their hand during the baseline and darkened conditions, which was evidenced by higher ratings given to the statement, *"the video hand belongs to me",* assessing the amount of hand ownership. During the crawling skin condition (static hand), participants with high-functioning autism still reported higher ownership over the visually manipulated hand compared to the control group whose ownership scores significantly dropped and on average participants disagreed with the ownership statement during the experimental condition. This indicates that individuals of typical development felt reduced ownership over their hand during the static condition because of the distorted appearance of their right hand, indicating a higher visual influence compared to those with autism. Furthermore, this is in line with the findings of Newport & McKenzie's (2015) study where distortion of an individual's own limb lead to participants disowning their own limb.

The results also indicate that, on average, respondents in the typically developing group reported feeling more somatosensations which was evidenced by higher somatosensory ratings to the statements assessing reports of sensations felt in the right hand during the static condition, however, individuals with HfA did not. Therefore, the results of the investigation suggest that individuals with HfA were less influenced by visual information compared to those of typical development. Non- somatosensory (control) statements were used to ensure that participants were attentive when rating statements. There were no significant differences found between the two groups for non- somatosensory statements, indicating that participants understood the statements and were accurate in responding.

The static hand illusion is a purely visual illusion that generates somatosensory sensations in the absence of any tactile input. Lower- level visual processing has been explored in autism and research indicates atypical sensory processing at a cursory level (Bebko et al., 2006; Marco et al., 2011). This has been explored using various illusionary paradigms, such as the Flash- beep illusion (Van Der Smagt et al., 2007), indicating that individuals with autism show a diminished effect of the illusion. Even though the illusionary paradigm being used in the current investigation is not similar to those been employed in the past, the results of the current investigation seem to indicate that lower- level visual information is affecting hand ownership for the participants of typical development, or in terms of the current investigation, viewing their hand in a visually distorted stance is affecting their judgements regarding their own hand. The results of the control group indicate that during the crawling skin condition, respondents lost ownership over their hand but reported higher number of illusory sensations felt. This suggests the impact of lower- level visual information i.e. the distorted image of the hand and the sensations being felt, in making judgements of their own hand. The change in appearance and feeling somatosensory sensations over their own hand could make it feel as an "alien hand" resulting in loss of ownership. However, this does not seem to be the case for the HfA group, as they reported equal ownership of hand during the baseline and experimental conditions and no reports of somatosensations.

The crawling skin illusion manipulates visual information; however, the location of the hand is always congruent to the video image of the hand. Research indicates, that susceptibility to the rubber hand illusion is not only determined by the visuo- tactile synchrony between the real and rubber hand, but knowledge about the location of the hand can also reduce the susceptibility to the illusion (Hohwy & Paton, 2010; Preston & Newport, 2015), which could be why individuals with autism show lesser proprioceptive drift. Tsakiris (2010) indicated that contextual differences between the fake hand and the real hand could potentially impact the susceptibility to the RHI. Studies that have employed the RHI paradigm to investigate multisensory integration in autism have suggested that individuals with autism are more reliant on proprioception which in turn reduces their susceptibility to the visuo- tactile synchrony resulting in more accurate judgements regarding the location of the hidden hand. Therefore, segregation of sensory input and one's cognitive knowledge could explain the results obtained in the current investigation. Hence, keeping in line with studies which indicate higher proprioceptive performance in individuals with autism, one could argue that during the crawling skin illusion there is less influence of visual information, however, as the hand stays in its original location, proprioceptive information could potentially be helping the HfA group in not feeling the visually induced somatosensations. If this is the case, it could be suggested that individuals with autism are not comprehending the global aspect of the illusion, whereas, they are also not integrating the lower- level sensory information (visual manipulation), which is why they are not experiencing the illusion. However, as this experiment was only limited to subjective rating's and a small sample size, no big conclusions can be drawn. Even though we see that individuals with HfA show a bias towards their own cognitive knowledge at the expense of the visual input; I will further discuss this in- depth during the general discussion, in order to investigate multisensory input further, other illusions will be used that manipulate more than just visual input.

Furthermore, the current study used subjective reports in order to measure the illusory experience of participants. However, it is difficult to establish whether the subjective reports of participants indicate differences in the experience of these sensations or due to demand characteristics in order to comply with the expectations of the experiment. Furthermore, keeping your hand still for three minutes would automatically generate feelings of numbness, which could potentially alter participant's judgements. However, if this were the case than we should have seen this trend in those with HfA as well as reports of feeling sensations in control conditions too. Furthermore, as previous studies have shown, individuals with autism tend to not comprehend the global aspect of an illusion, whereby, they show superior lower- level sensory processing. Therefore, it could be the case that when individuals with autism are presented with unimodal illusions, they are less prone to succumb towards it, however, when multiple sources of sensory input are presented they tend to be selective in which input to process. If later is the case, then in the following experiments individuals with autism will be presented with a multisensory illusion which manipulates both visual and tactile information in order to test whether superior lower- level processing is more apparent under a different illusion and also if individuals with autism and those with high autism traits are selective in processing which information to attend to. More so, previous research has indicated that even though tactile information is an external sensory source and proprioception is an internal source, there seems to be an interaction between the two sources of information, where one source can simultaneously affect the other (Rincon-Gonzalez et al., 2012). Therefore, the following chapters will address these issues by using an illusion which stimulates multiple sources of sensory information. With the use of the MIRAGE system a more dynamic multisensory illusion, the finger stretching illusion (Newport et al., 2015) as this involves the interplay of visual, tactile and proprioceptive information. Previously, it has been shown that individuals of typical development are extremely susceptible towards it (Newport et al., 2015), therefore, the following chapter will explore the susceptibility of those with high and low autism traits towards this illusion. Furthermore, subjective ratings can only tell us very little regarding susceptibility, therefore, objective measures will be introduced in order to confirm whether individuals with high and low autism traits and those with HfA embody the illusion or not.

Chapter Four

Experiment Three

Susceptibility to a finger stretching (Visuo, tactile and proprioceptive) illusion in Individuals with High and Low Autism Traits

4.1. Introduction

Differences in susceptibility to the multisensory illusions have been explained in terms of having an atypical temporal binding of lower- level sensory processes which in turn effects the embodiment of an object or artificial limb (Cascio et al., 2012; Greenfield et al., 2015). While others have argued that the reduced effect of the illusion is due to top- down contextual knowledge not being integrated with the current sensory input (Palmer et al., 2013), suggesting that individuals with autism tend to over- rely on a single sensory source, such as proprioception. MIRAGE mediated reality device has been used in various investigations, where realistic bodily illusions have been provided to individuals with autism (Greenfield et al., 2015) and typically developing individuals (Newport et al., 2015), highlighting a strong sense of ownership, as opposed to other bodily illusions where an individual needs to incorporate an external object (Palmer et al., 2013). One such example is the finger stretching illusion (Newport et al., 2015). The finger stretching illusion is a very dynamic and powerful illusion, where, in a recent study 593 children (aged 8 – 15) were presented with a forced choice task asking them to state whether "it felt like his or her finger had really been stretched". A total of 93% of the population tested using the finger stretching illusion reported the illusion and said that their finger had really been stretched.

The finger stretching illusion is a multisensory illusion during which the live video image of participants own right index finger is visually stretched. This works in such a way that the participant views his or her right index finger through the MIRAGE system and the experimenter grasps the tip of the extended index finger and pulls it gently, during which the participant views his or her finger being stretched in real-time. Even though the stretch is just a visual one, the synchrony between the visual stretch and tugging of the index finger gives rise to the illusory experience of having one's finger being stretched. This illusion is extremely compelling as it is presented on the participants own finger and it helps in differentiating the top- down and bottom- up aspects of the illusion itself, where the former is based on the existing knowledge one has regarding their own body part and the later can be manipulated to present synchronous or asynchronous visuo-tactile information. Previous studies that have used multisensory illusions in order to investigate sensory integration in autism have mostly focused on visual and auditory inputs (Shams et al., 2002; Stekelenburg et al., 2013; Stevenson et al., 2014) or tactile perception (Brett-Green et al., 2008; Ro et al., 2009; Marco et al., 2012) , whereas, limited studies have employed methods that can comprehensively study visuo- tactile integration in autism. As the finger stretching illusion has been tested widely in the general population (Newport et al., 2015), it provides us with an alternative tool in understanding how individuals with autism integrate visual and tactile information.

One of the leading theories of autism, the weak central coherence theory (Happé, 2005), argues that individuals with autism present a unique perceptual style where they show limited ability to understand context or a failure to see the bigger picture. Therefore, indicating that they are more locally- driven or sensory- driven. Similarly, the enhanced perceptual functioning theory (Mottron et al., 2006) argues that people with autism tend to display an increased attention to sensory stimuli and that causes the atypical cognitive and behavioral deficits. On the other hand, one of the newest theories of sensory perception in autism, over-reliance on proprioception (Paton et al., 2012; Palmer et al., 2013), argues that individuals with autism tend to over- rely on a single sensory source, i.e. proprioception, at the expense of integrating multiple sources. This theory binds in with the WCC theory as an over- reliance on proprioception would indicate that individuals with autism are sensory driven. What all these theories have in common is the idea that there seems to be a tendency to rely on sensory information in autism, while ignoring the overall picture. Therefore, the finger stretching illusion provides us with a great way to investigate these claims as this illusion provides us with a clear distinction regarding whether participants integrate the co- current sensory information with their top- down knowledge regarding their body or if they exclusively choose one over the other. Furthermore, if individuals with autism are sensory driven, we would see difference's in integration where they would be less susceptible towards the illusion.

In the current experiment, individuals with high autism traits and low autism traits were subjected to the finger stretching illusion in order to investigate the effects of the multisensory illusion using the MIRAGE mediated reality system. Previous studies, such as the RHI, has presented mixed results as they have demonstrated lower ownership but higher proprioceptive reliance when experiencing the illusion (Palmer et al., 2013). Individuals with autism tend to be detailed- oriented and research suggests that they are more reliant on top- down knowledge when interacting with the external environment and this is even consistent for individuals with high autism traits, however, to a lesser severity. Based on the results of the first two experiments in this thesis, the results have highlighted high- ownership scores for both the HfA and the autism traits population, indicating that both groups give ownership to their virtual hand.

In the current investigation, individuals with high and low autism traits were asked to report the subjective experience using an illusory experience questionnaire, along with making judgements regarding the location of the fingertip. I also investigated the individual aspects of the illusion, where participants were subjected to two extra conditions (i) a visual stretch condition during which no tactile input was provided and (ii) a Tug condition where no visual manipulation to the finger was delivered. During both these conditions, participants made verbal judgements regarding the experience of the illusion, as well as made judgements regarding the location of the fingertip. As a control for the finger estimation task, participants were also required to make estimates regarding their right index finger knuckle (third joint) as a control for the finger estimation task.

The hypothesis for the current investigation is based on two factors, firstly, the results of the previous investigation showed high ownership for both high and low AQ groups, therefore, a similar pattern is expected in the current investigation. Secondly, because it has been suggested that individuals with high autism traits, similar to those with autism, tend be more reliant on proprioception, it is expected that their judgements regarding the fingertip will be more accurate. This idea has been previous presented in studies that have employed the RHI paradigm where it has been shown that participants with high AQ scores tend to show a lesser proprioceptive drift i.e. they reach for their real hand after visual tactile stimulation, and this has been argued as a result of higher reliance on proprioception while disregarding the visuo-tactile sensory information. Therefore, keeping in line with these ideas, I hypothesize that the synchronous stretch condition will generate the strongest illusion effect but only for participants in the Low AQ group. In terms of ownership scores, participants in the high AQ group should have high ownership scores across all conditions. This is in line with previous investigations (see chapter 2 and 3) where high AQ scorers had high ownership scores across all conditions. For the low AQ group, I predict a similar pattern of results, where they would report high ownership across all conditions, except for the visual stretch condition. In terms of illusion strength ratings, I predict that the low AQ group would report the highest illusion strength ratings, however, individuals in the high AQ group would be less susceptible to the visuo-tactile synchrony during the synchronous stretch condition. The illusion strength ratings during the visual stretch and tug conditions would not generate positive ratings for both groups. For the estimation task, perceived judgement of the fingertip should drift the most from the actual location of the fingertip to the stretched tip only during the synchronous stretch condition but only for the low AQ group and not for the high AQ group, as their estimation of the fingertip would be closer to the actual fingertip. This is in line with previous studies that have used the estimation tasks in the non- clinical autistic populations (Palmer et al, 2015). This difference in estimation would only be visible in the synchronous stretch condition, as the visuo-tactile synchrony during this condition generates strong sense of ownership, which in turn effects the judgement. Lastly, participants in both groups would make judgement closer to their actual fingertip during the visual stretch and tug conditions.

4.2. Methods

4.2.1 Design

A mixed design was used with group being the between subjects-factor (High AQ vs Low AQ) and condition being the within-subject factor (Baseline vs Visual Stretch Vs Tug Vs Synchronous stretch conditions), and the dependent variables being ownership ratings, illusion susceptibility ratings and finger estimation scores.

4.2.2. Participants

Participants were recruited based on their scores on the Autism Quotient (AQ) (Baron-Cohen et al., 2001a). The Autism Spectrum Quotient, along with a modified version of the Edinburgh handedness inventory (EHI) (Oldfield, 1971) were distributed online using Qualtrics. A total of forty- four (44) right- handed participants (Mean age of sample 22.68, SD: 3.01) were selected to take part in the study. Ethical approval for experimental procedures was obtained and approved by the Faculty of Science Research Ethics committee, University of Nottingham. Based on the score on the AQ, individuals scoring a total of 32 and above were allocated into the high AQ group, whereas, participants scoring lower than 32 were allocated into the low AQ group. The high AQ group consisted of twenty-two (22) participants (Mean age: 22.72, SD: 3.04) consisting of twelve (12) males and 10 females, with an average AQ score of 36.50 (4.59). There were nine males and 13 females in the low AQ group (Mean age in years: 22.63, SD: 3.03) with an average AQ score of 18.36 (5.27). Participants were not informed about their AQ scores and group allocation until after all experimental procedures were completed. Written and informed consent was obtained prior to participation. All respondents reported normal or corrected to normal vision, and no sensory deficits. It is also important to note that participants in this study were not the same as the ones who took part in experiment 1 (Chapter 2).

4.2.3. Materials

4.2.3a. Questionnaires

The Autistic Quotient (AQ) (Baron-Cohen et al., 2001a) was used in order to assess the number of autistic- like traits an individual had. The AQ has been used widely in the popular literature as a measure of screening for non- clinical levels of autistic traits in the typically developing population (Sutherland & Crewther, 2010; Bayliss & Kritikos, 2011; Palmer et al., 2013) . A score of 32 and above on the AQ has been suggested as an indication of greater similarity to traits of autism (Baron-Cohen et al., 2001a)

A modified version of the Edinburgh handedness inventory (EHI) (Oldfield, 1971) was also used to ensure participants were right- handed. This self- report inventory evaluates the participants dominant hand usage in everyday activities, such as writing, holding a spoon, throwing, etc. This was controlled for as all participants taking part in this experiment were right- handed[10].

An Illusion experience questionnaire was used to measure the subjective experience of the participants during the MIRAGE investigation. This consisted of three statements in total: (i) ownership statement to assess experience of finger ownership during the experimental conditions, (ii) illusion strength statements that were used as a measure of illusion susceptibility and (iii) a control statement that was used as attention filler. The ownership and illusion strength statements were modified based on previous investigations using the MIRAGE illusion (Newport et al., 2010). The control statement was used as attention filler and was not associated with the illusionary experience. Table 4.1 shows the statements used during the MIRAGE investigation[11]. Previous investigations that have used the MIRAGE system to deliver the finger stretching illusion have used multiple statements to measure susceptibility and ownership (Newport & Giplin, 2011; Ropar et al., 2018), however, for the current

[10] The EHI does not guarantee handedness- the modified version used in the current investigations was used only to control for participants handedness or to ensure they were all dominant right-hand users in daily activities. This was done so because bodily illusions are stronger when administered on participant's dominant hand.
[11] The illusion experience questionnaire was reduced to consist of only three statements, compared to previous investigations. This was done for two reasons, firstly, due to reduce the experiment time, as objective measures were added to the task, and secondly, a comparison analysis was run between three groups of statements to determine which one produced the strongest rating. Therefore, the questionnaire was modified.

investigation only one ownership statement, one illusion strength statement and one control statement was used. This was done to reduce the experiment time as objective measures were introduced in order to measure illusion ownership and embodiment and also because when looking at the individual scores from statements of the three factors from experiment two, the one's which generated the highest ownership, susceptibility and control scores were selected. Furthermore, asking participants statements of similar nature could lead them to responding in a way that is less accurate, such as asking them about their hand in different ways could affect their judgement scores. Participants made verbal judgements on a 7.0 rating scale for which -3 indicated strong disagreements, 0 denoted neutral and 3 indicated strong agreement with the statement. All statements were presented to participants in a random order, counter balanced between each participant and condition.

Item Type	Text (Statement)
Ownership	The finger that I see is a part of my body
Illusion Strength	It felt like my finger was really being stretched
Control	My hand finger feels warmer than usual

Table 4.1 Statements used to measure finger ownership and illusion susceptibility of respondents across all conditions during the MIRAGE investigation

4.2.3b. Objective Data

Experimental Conditions and MIRAGE system

The Finger stretching illusion (Newport et al., 2015) was presented to the participants, along with a baseline condition and two control conditions. All participants were presented with the baseline condition first to minimize the illusion carry- over effects. During the (i) baseline condition, no illusionary manipulation was applied to the participant's right index finger. They were required to verbally rate the illusion experience statements, after which they made estimates regarding the location of the fingertip. During the (ii) Visual stretch condition the image of the participant's right index finger was visually stretched for a total of 150 pixels (2.5 inches) in increments of three (50 pixels per stretch) but without any tactile input. After the finger was visually stretched, participants rated the illusionary statements and made estimations regarding the location of the fingertip. During the (iii) tug- no stretch condition, the experimenter grasped the distal phalanx (end) of the index finger and gently pulled the tip to straighten the ligaments of the finger, but not enough to cause any discomfort. During this condition, participants did not view their finger being visually stretched. In the final (iv) Synchronous stretch condition, a small wooden block was used by the experimenter which was placed against the fingertip and the participant verbally indicated whether they could feel the block being touched. After this, the block was moved further away. After which, the experimenter grasped the distal phalanx (end) of the index finger and gently pulled the finger, without causing any discomfort. Simultaneously, the area of the live video corresponding to the middle knuckle of the index finger expanded in such a way that the visible area gradually doubled outwards. This was done in an increment of three (50 pixels per stretch/ pull), ensuring that the stretching of the video image and grasping the index finger were completely synchronous. After the finger was stretched, the wooden cube was touched against the fingertip and the participants were required to rate the illusion experience statements and make estimates of the location of their actual fingertip.

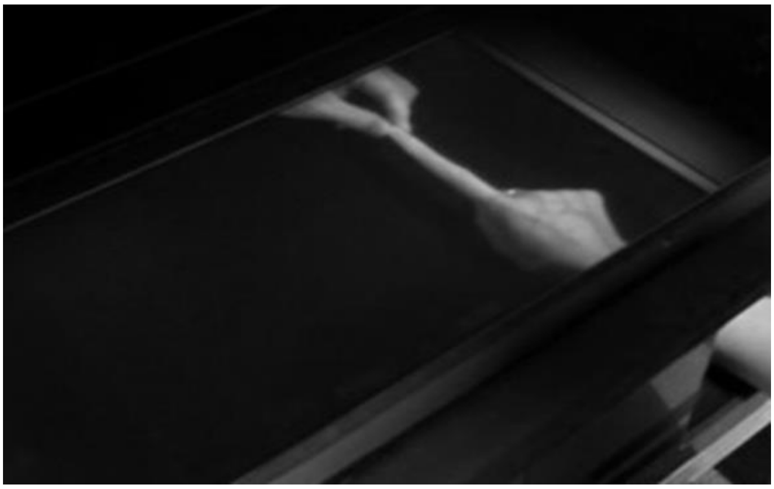


Fig. 4.1 The finger stretching illusion that was presented to the participants. The image shows the synchronous stretch condition (experimental condition) from the participants view

The baseline condition was always presented to participants first in order to avoid any carry over effects. All other conditions were conducted in a counterbalanced order between participants. The visual stretch and tug conditions were also used as control conditions, as these conditions were hypothesized to generate no effect of the illusion. As a control measure for the fingertip estimation task, participants were required to make judgements regarding the location of the metacarpophalangeal joint of the right index finger (first knuckle on the right index finger which connects the finger to the hand). This was used as a control measure as the finger stretching illusion is directed towards the finger and should have no effect on the knuckle.

After each visual condition, participants were required to make judgements regarding the location of the right index finger. This was done immediately after participants rated the illusion experience questionnaire. A black screen overlaid the screen that displayed the participants' hand, after which a red horizontal line would move vertically starting either from the top or the bottom of the screen. In either case, participants made two judgements, one when the red line moved from the top and the second one when the line appeared from the bottom of the screen. As a control measure, participants made estimates regarding the location of the knuckle of the index finger.

Fig.4.2a Participant view for the fingertip estimation task. The red line spread horizontally would move up and down the screen. Participants would verbally ask the experimenter to pause the line when they thought it was aligned with the tip

Fig.4.2b Experimenter view of the fingertip estimation task. The yellow line was used a start point for each participants fingertip; such that their actual fingertip was always aligned with this line. Participant's fingertip was stretched after this point.

4.2.4. Experimental Procedure

All participants completed the task using the MIRAGE mediated reality device that presented live video images of their right hand in real time from the participant's perspective; which was in the spatial location of their own hand.

Participants sat on a chair in front of the MIRAGE, ensuring that they could view their right hand when they placed it onto the work surface of the MIRAGE device. A rectangular black bib attached across the length of the MIRAGE was tied comfortably around the participant's shoulders to obscure a direct view of their upper arm. Participants were instructed to place their right hand inside the MIRAGE system and underwent a brief acclimatization period (approximately 40 seconds) during which they were allowed to move their hand around in order to familiarize themselves with the MIRAGE set up. During this period the experimenter verbally explained the task that the participants were required to perform.

All participants started with the baseline condition. Participants rated the illusion experience questionnaire after which they made judgements of regarding the fingertip and the knuckle of index finger. Following the baseline condition, participants were presented with the rest of the conditions and in each condition, they were required to rate the illusion experience questionnaire and make estimates regarding the fingertip and the knuckle of the index finger. During each condition, participants made estimation of the fingertip twice, from top to bottom and then from bottom to top. This was done to control for the estimations and as a reference to ensure that participants understood the task. The knuckle estimate was done in the same way. The order in which participants made judgements was also counterbalanced between participants.

4.3. Results

Subjective ratings were collected using an illusion ownership questionnaire. Objective data was collected through judgements regarding the location of the index finger in each of the conditions after the image was manipulated. For each set of data, it was analyzed using a 4 *(Conditions: Baseline Vs Visual Stretch Vs Tug Vs Synchronous Stretch)* x 2 *(Groups: High AQ vs Low AQ)* Repeated Measures ANOVA with conditions as the within- items factor and groups as the between- subjects factor. Pairwise comparisons (Bonferroni- corrected) were used to assess any main effects and independent samples t- tests (Bonferroni corrected) were computed to test any significant interactions.

4.3.1. Subjective Ratings

Respondents verbally scored a single ownership, illusion strength and a control statement in four different conditions *(baseline, visual stretch, tug and synchronous stretch conditions)*. Ratings were made on a -3 to 3 rating scale, where -3 denoted disagreement and 3 referred to strong agreement with the statements. Similar to previous investigation, the rating scale was changed to negative to positive values to make it less ambiguous for the participants. Furthermore, using a rating scale with both positive to negative values has been shown to be more effective in recording responses (Raftery et al., 2013).

4.3.2. Control Statements

Respondents' ratings for the control statement "*my hand feels warmer than usual*" were analyzed using a Repeated Measures ANOVA. A 4 (conditions) x 2 (groups) ANOVA revealed no significant main effect of condition, $F (2, 42) = 2.47, p = 0.82$ ($\eta^2 = .056$). There was also no significant interaction reported between groups and conditions, $F (2, 42) = .99, p = .40$ (η^2

= *0.23)*, indicating that there were no significant differences between the ratings given for the control statement by the high and low AQ groups within conditions (Fig 4.3)

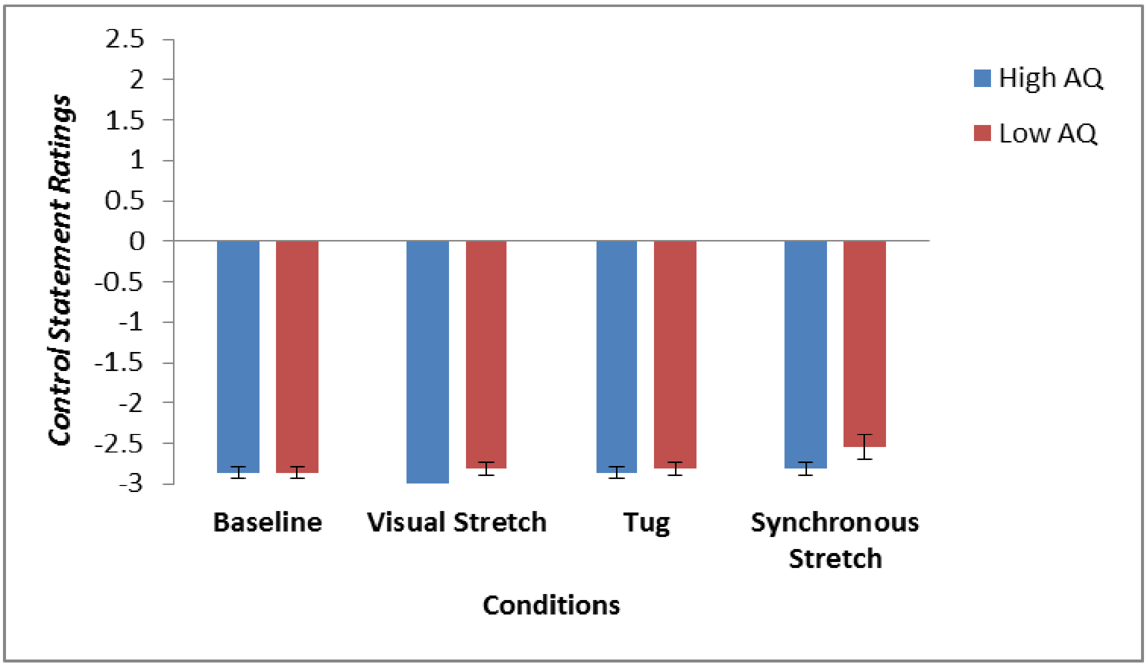


Fig 4.3 Graphical representation of subjective ratings given for the statement "my hand feels warmer than usual" which was used as a control statement. No significant differences in means were found between the high and low AQ groups across conditions, as viewed by the overlapping error bars, as both groups disagreed with statement (as suggested by the negative ratings).

4.3.3. Ownership Ratings

In order to examine the differences in ownership felt over the finger during the various conditions, ratings to the ownership statement *"the finger that I see is a part of my body"* were used as a mean ownership score for each participant. A 4 x 2 Repeated Measures ANOVA revealed a significant main effect of condition, $F\ (2,\ 22) = 125.26,\ p < .001\ (\eta^2 = .749)$ indicating differences in ownership ratings. Pairwise comparisons (Bonferroni- corrected) revealed a significant difference in ownership rating during the baseline and visual stretch conditions, $p < .001$, $(\eta^2 = .533)$, suggesting that groups reported higher ownership during the baseline condition *(Mean: 2.79, SD: 0.41)* compared to the visual stretch condition (Mean: 0.45, SD: 1.93). There was no significant difference in ownership ratings between the baseline and tug conditions, *p =. 243,* (η^2 *= .322)*, indicating that respondents felt similar amounts of ownership over their finger during the baseline *(Mean: 2.79, SD: 0.41)* and tug *(Mean: 2.57, SD: 0.50)* conditions. Furthermore, no significant difference in ownership ratings were found between the baseline and synchronous stretch conditions, *p = 1.00,* (η^2 *= .581)*, indicating that respondents had similar ownership scores during the baseline *(Mean: 2.79, SD: 0.41)* and synchronous stretch condition *(Mean: 2.75, SD: 0.44)*. A significant difference in ownership scores was found between the visual stretch and tug conditions, $p < .001$, (η^2 *= .583),* indicating that groups reported higher ownership over the finger during tug condition *(Mean: 2.57, SD: 0.50)* compared to the visual stretch condition *(Mean: 0.45, SD: 1.93)*. Furthermore, there was a significant difference in ownership ratings during the visual and synchronous stretch conditions, *p = .001,* (η^2 *= .662)*, indicating that participants felt higher ownership over the finger during the synchronous stretch condition (*Mean: 2.75, SD: 0.44)* compared to the visual stretch condition *(Mean: 0.45, SD: 1.93)*. There were no significant differences found between the tug and synchronous stretch conditions, *p = .443,* (η^2 *= .381)*, indicating similar amount of ownership reported during the tug *(Mean: 2.57, SD: 0.50)* and synchronous stretch conditions *(Mean: 2.75, SD: 0.44)*. No significant effect of group was found for ownership ratings, $F(2, 28) = 2.63$, $p = .116$ ($\eta^2 = .086$)

More importantly, there was a significant interaction between conditions and groups, $F(2, 22) = 61.74$, $p < .001$ ($\eta^2 = .595$). Post hoc independent samples t- tests (Bonferroni-corrected) revealed no significant differences in ownership scores between the high and low AQ groups in the baseline condition, *p = 7.16,* (η^2 *= .442)*. A significant difference in ownership ratings was found between groups during the visual stretch condition*,* $t(2, 42) = 9.71$, $p < .001$, (η^2 *= .061)*, indicating that the visual stretch of the image of the participant's finger resulted in a drop of ownership for the low AQ group *(Mean: -1.14, SD: 1.42)* but not for the high AQ group *(Mean: 2.05, SD: 0.58)*. There were no significant differences in ownership ratings during the tug condition, $p = .373$, ($\eta^2 = .051$), indicating that participants in the high and low AQ groups reported similar amounts of ownership over their finger. Furthermore, no significant difference in ownership ratings was found between groups during the synchronous stretch conditions, $p = .735$ (Fig 4.4).

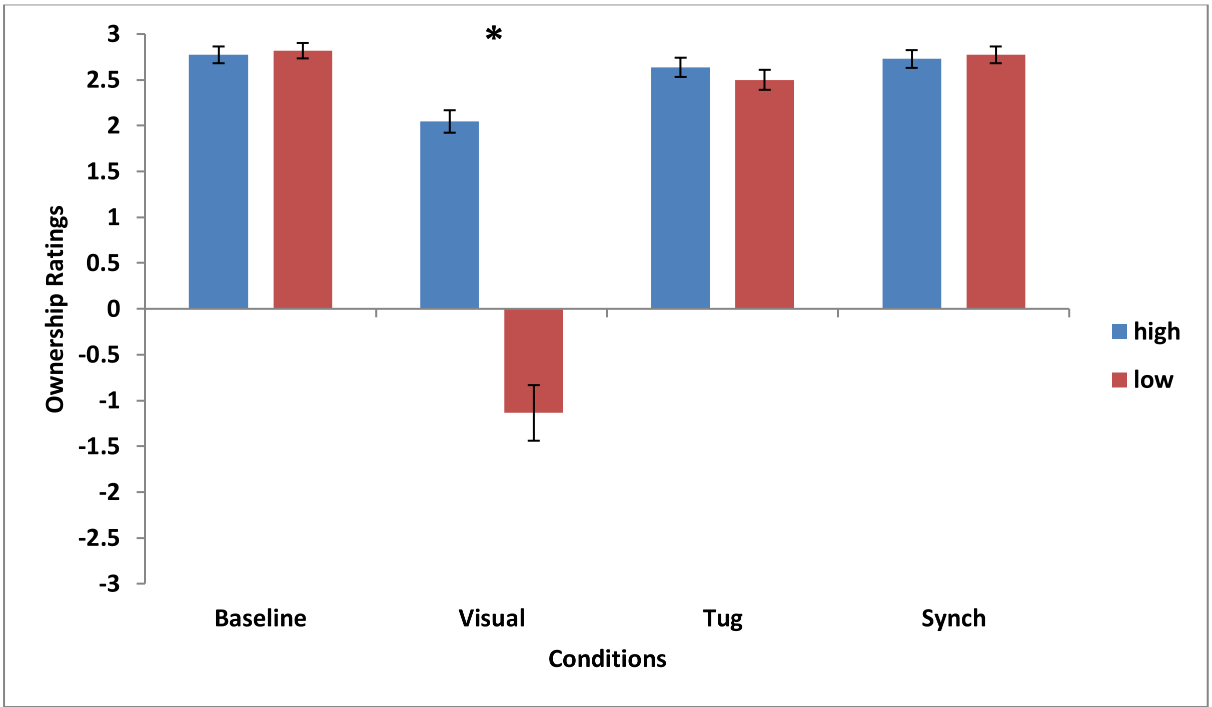


Fig 4.4 Mean ownership ratings for High (blue) and Low (red) AQ groups across all conditions. The bar chart indicates no significant differences in mean ownership ratings between the high and low AQ groups during the baseline and tug conditions as displayed by the overlapping error bars. Ownership ratings dropped for the low AQ group during the visual stretch condition for both groups. Furthermore, there were no differences in mean ownership ratings during the synchronous stretch condition as respondents in both groups strongly agreed to the ownership statement

4.3.4. Illusion Strength Ratings

Illusion strength ratings were used as a subjective measure to amount the level of susceptibility participants felt over their finger in each of the conditions. Ratings to illusion strength statement *"it felt like my finger was really being stretched"* were used as a mean susceptibility score for each of the participant. Repeated Measures ANOVA revealed a main effect of condition, $F (2, 42) = 391.25, p < .001$ ($\eta^2 = .903$), indicating differences in illusion strength ratings. Pair wise comparisons (Bonferroni- corrected) revealed a significant difference in ratings between the baseline and visual stretch condition, $p < .001$, ($\eta^2 = .566$), suggesting that participants gave higher susceptibility ratings during the visual stretch condition (*Mean: - 2.39, SD: 0.84)* compared to the baseline condition *(Mean: -3.00, SD: 0.00)*. A significant difference in susceptibility scores was found between the baseline and tug conditions, $p = .018$, ($\eta^2 = .440$), indicating that participants had higher ratings in the tug condition *(Mean: - 2.81, SD: 0.39)* compared to baseline condition *(Mean: - 3.00, SD: 0.00)*. A significant difference in susceptibility rating was also found between the baseline and synchronous stretch conditions, $p < .001$, ($\eta^2 = .898$), indicating higher ratings given by respondents during the synchronous stretch condition *(Mean: 0.11, SD: 2.73)* compared to the baseline condition *(Mean: -3.00, SD: 0.00)*. A significant difference in ownership ratings was also found between the visual stretch and tug condition, $p = .003$, ($\eta^2 = .672$), indicating higher susceptibility scores during the visual stretch condition *(Mean: -2.38, SD: 0.84)* compared to the tug condition *(Mean: - 2.81, SD: 0.39)*. A significant difference in ratings was also found for the visual stretch and synchronous stretch conditions, $p < .001$, ($\eta^2 = .883$), indicating that susceptibility scores were higher during the synchronous stretch condition *(Mean: 0.11, SD: 2.73)* compared to the visuals stretch condition *(Mean: - 2.38, SD: 0.84*). Furthermore, there was also a significant difference in scores between the tug and synchronous stretch conditions,

p < .001, (η^2 = .711), suggesting that participants had higher ratings during the synchronous stretch condition *(Mean: 0.11, SD: 2.73)* compared to the tug condition *(Mean: -2.81, SD: 0.39).* However, the analysis revealed no significant effect of groups for illusion strength ratings, *F (2, 28) = 1.19, p = .285 (η^2 = .041).*

There was also a significant interaction between groups and conditions, *F (2, 42) = 294.77, p < .001 (η^2 = .875).* Four independent samples post hoc t- tests (Bonferroni-corrected) revealed no significant differences in illusion strength ratings between the high and low AQ groups during the baseline condition, *p > .05, (η^2 = .416).* Both groups average susceptibility score *was (Mean: – 3.00, SD: .00)* indicating that respondents strongly disagreed with the statement asking them whether they felt like their finger was being stretched. Also, there was no significant difference in susceptibility scores between groups during the tug condition, *p = .12, (η^2 = .338).* A significant difference in ownership ratings was found between groups during the visual stretch condition, *t (2, 42) = - 3.93, p < .001, (η^2 = .719),* suggesting that respondents in the low AQ group *(Mean: - 1.95, SD: 0.95)* compared to the high AQ group *(Mean: - 2.81, SD: 0.39)*. Even though the results indicate a difference in ratings, however, both the groups had negative scores suggesting that respondents in both groups, overall, disagreed with the statement measuring illusion strength, but there was a variation in disagreement. Furthermore, there was a significant difference between groups during the synchronous stretch condition, *t (2, 42) = - 33.98, p < .001, (η^2 = .823),* indicating that participants in the low AQ group were more susceptible to the finger stretching illusion *(Mean: 2.77, SD: 0.42)* compared to the high AQ group *(Mean: - 2.55, SD: 0.59).* This is evidenced by the positive ratings given by the low AQ group during the synchronous stretch condition, whereas, the high AQ group reported feeling illusory effect (Fig 4.5).

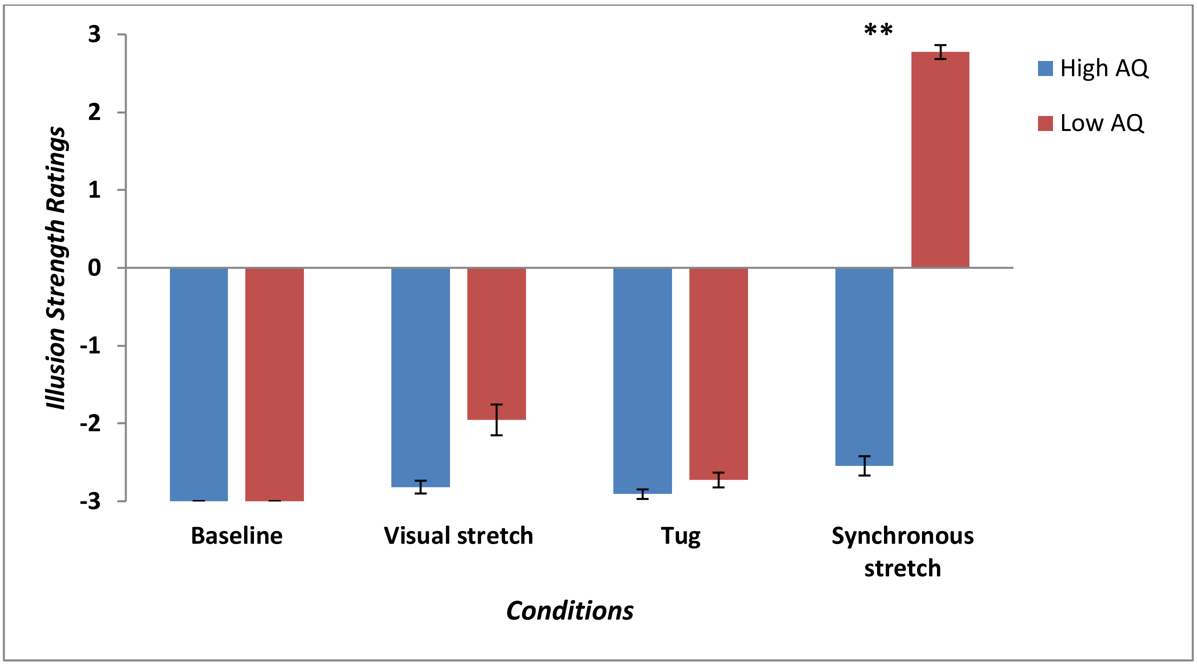


Fig. 4.5 Mean illusion strength ratings for the High (blue) and Low (red) AQ groups across all conditions. The bar chart indicates no significant difference in illusion strength ratings between the high and low AQ groups during the baseline and tug condition. There was a significant difference in illusion strength ratings in the visual stretch condition, however, variation in scores were below the score of "0" indicating disagreement. There was a significant difference in illusion strength ratings during the synchronous stretch condition, whereby, the high AQ group disagreed more with the statement compared to the low AQ group.

4.3.5. Objective Measures

Data collected regarding the fingertip and knuckle estimate was in pixels. Values for each participant, in pixels, were than subtracted from the location of the real fingertip. The difference between the estimate and the real fingertip was then converted into inches; after which SPSS was used to further analyze the data. For example, all participants real fingertip was always placed at 300 pixels after which the finger was visually stretched to a total of 150 pixels, so the participant would view their finger to the 450-pixel point. When making the estimate, participant would have to make judgements regarding the actual fingertip. Later, when the data was analyzed, the original point where the fingertip was considered as a ‘0’ and the point of the visually stretched finger was denoted as 2.5 inches.

4.3.6. Location Estimates

Knuckle Estimate (control)

No subjective ratings were obtained for the participants knuckle estimates, as the illusion has no effect on the location of the knuckle. As a control for the fingertip estimates, participants were required to make judgements regarding the knuckle of the index finger. As the illusion is finger specific, the estimate of the knuckle was used as a control measure because this should not have been affected. A 2 (groups) x 4 (conditions) Repeated Measures ANOVA revealed no significant main effect of condition, $F(2, 42) = .351$, $p = .734$ ($\eta^2 = .041$), indicating that there were no variances in knuckle estimates between conditions. Furthermore, there was no significant interaction between groups and conditions, $F(2, 42) = 535$, $p = .671$ ($\eta^2 = .010$), indicating that participants estimate’s regarding the location of their knuckle did not differ between groups across conditions (Fig. 4.6). However, as seen in Figure 4.6, none of the groups were accurate in determining the location of the knuckle and this can be attributed to two factors; i). the expectance of viewing the finger getting longer would generate an effect over the perceived location of the knuckle, i.e. if the finger is getting longer, the knuckle would move further up, or ii). the slight drift seen in the estimation can be due to task difficulty.

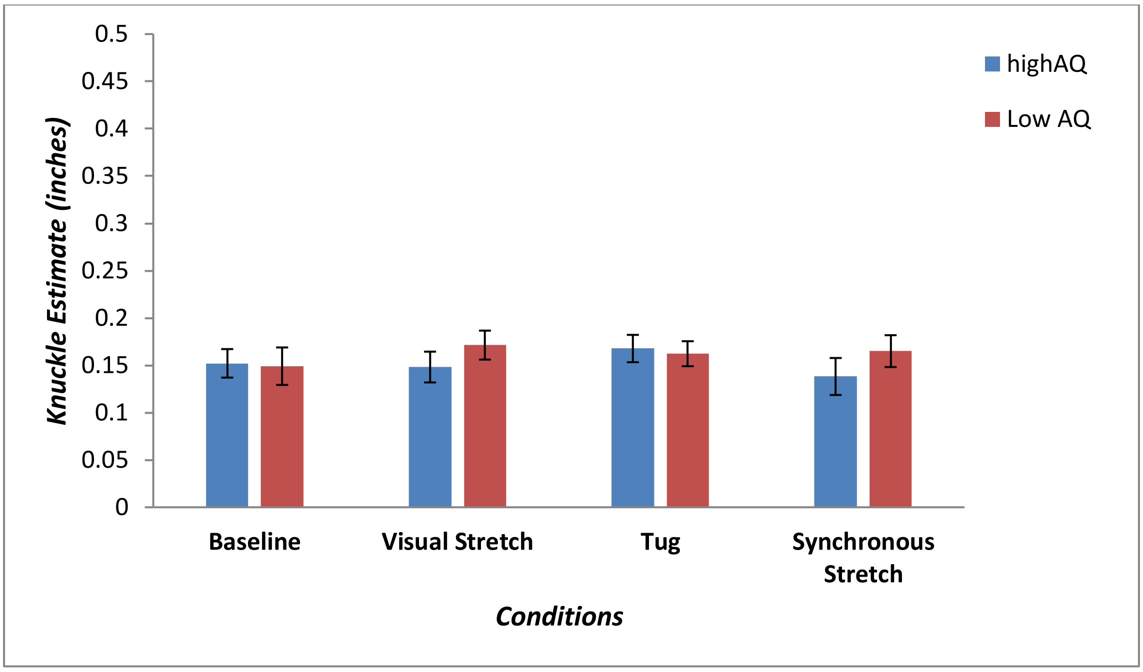


Fig 4.6 Mean estimate scores for High (blue) and Low (red) AQ groups across all conditions. The bar chart indicates no significant differences in estimating the location of the knuckle of the index finger (Metacarpophalangeal joint) across all conditions. This was used a control measure for fingertip estimation task

Fingertip Estimation

A 2 (Groups: high Vs Low) x 4 (Conditions: baseline x visual x tug x synchronous stretch) Mixed ANOVA revealed a significant main effect of conditions, *F (2, 42) = 59.029, p < .001* (η^2 = .584), indicating a difference in estimates between conditions. Pairwise comparisons revealed no significant differences in fingertip estimation between the baseline and visual conditions, *p = 1.00, (*η^2 *= .615)*, indicating that there was no difference in fingertip estimates during the baseline condition *(Mean: 0.636, SD: .389)* and the visual condition *(Mean: .738, SD: .449)*. There were also no significant differences in estimates between the baseline and tug conditions, *p = 1.00, (*η^2 *= .509)*, indicating that fingertip estimates did not differ significantly between the baseline *(Mean: 0.636, SD: .389*) and tug conditions *(Mean:*

0.601, SD: .368). A significant difference was found between the baseline and synchronous stretch conditions, $p < .001$, ($\eta^2 = .819$), indicating that fingertip estimates were closer to the real finger during the baseline condition *(Mean: 0.636, SD: .389)* compared to the synchronous stretch condition *(Mean: 1.417, SD: 1.08)*. Furthermore, fingertip estimates did not differ during the visual and tug conditions, $p = 1.00$, ($\eta^2 = .616$), indicating that estimates in the visual condition (Mean: .738, SD: .449) and the tug condition *(Mean: 0.601, SD: .368)* were similar. A significant difference in mean estimation score was found for the visual and tug conditions, $p < .001$, ($\eta^2 = .554$), indicating that scores were lower during the visual condition *(Mean: .738, SD: .449)* compared to the synchronous stretch condition *(Mean: 1.417, SD: 1.08)*. There was also a significant difference in estimation scores between the tug and synchronous stretch conditions, $p < .001$, ($\eta^2 = .682$), indicating that respondents had lower scores during the tug condition (*Mean: 0.601, SD: .368)* compared to the synchronous stretch condition *(Mean: 1.417, SD: 1.08*).

There was also a significant interaction between groups and conditions, $F(2, 42) = 74.371$, $p < .001$ ($\eta^2 = .569$). Post Hoc independent sample t- tests (Bonferroni- corrected) revealed no significant difference in estimation scores between high AQ and low AQ groups during the baseline condition, $p = .364$, ($\eta^2 = .422$), indicating that respondents in the high AQ group *(Mean: 0.583, SD: 0.418)* and low AQ group *(Mean: 0.691,* SD*: 0.361)* had no significant difference in estimates made regarding the fingertip. A significant difference in estimation scores was found between groups during the visual condition, $t(2, 42) = -4.547$, $p < .001$, ($\eta^2 = .511$), indicating that respondents in the high AQ group *(Mean: 0.482, SD: 0.311)* had significantly lower estimation scores compared to the low AQ group *(Mean: 0.993, SD: 0.424)*. A significant difference in estimation scores between conditions was also found for the tug condition, $t(2, 42) = -4.045$, $p < .001$, ($\eta^2 = .781$), indicating that respondents in the high

AQ group *(Mean: 0.408, SD: 0.334)* had lower estimation scores in tug condition compared to the low AQ group *(Mean: 0.794, SD: 0.297)*. There was also a significant difference in estimation scores between groups during the synchronous stretch condition, $t\ (2, 42) = -18.301$, $p < .001$, ($\eta^2 = .786$), indicating that respondents in the high AQ *(Mean: 0.41, SD: 0.23)* group has lower estimation scores compared to those in the low AQ group *(Mean: 2.42, SD: 0.461)* (Fig 4.7).

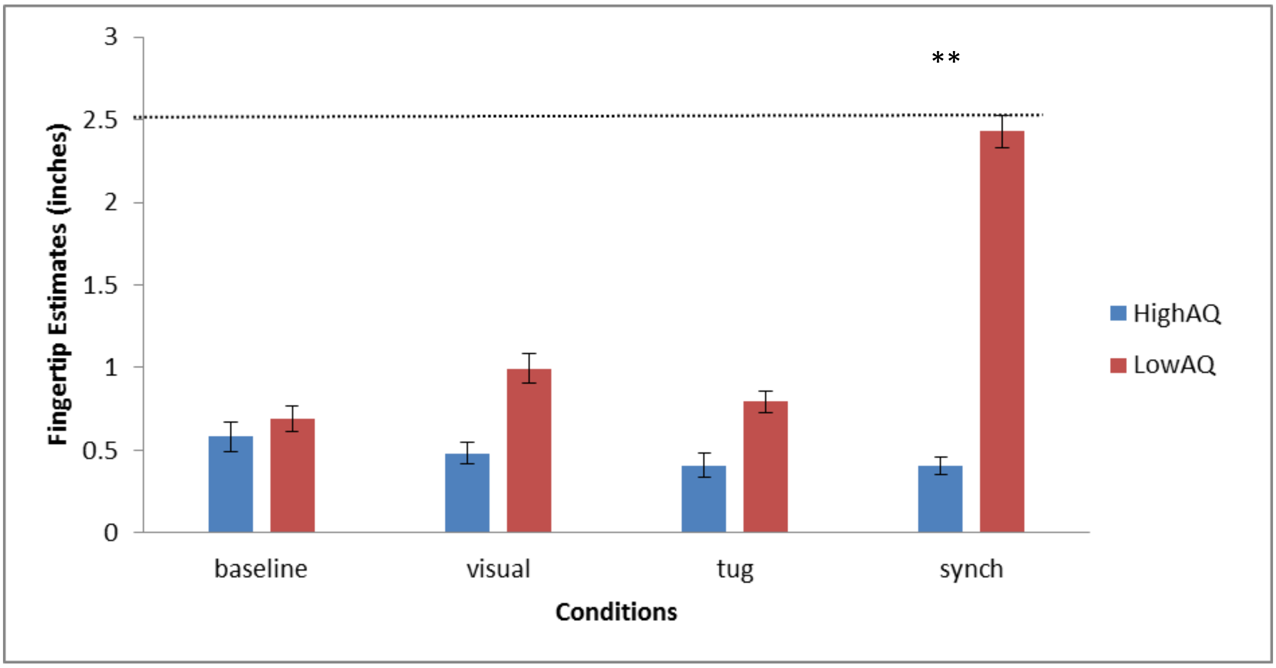


Fig 4.7 Mean estimation scores for the High (blue) and Low (red) AQ groups across all conditions. The bar chart indicates no significant difference in estimating the location of the fingertip in the baseline condition. There were significant differences between groups across all other conditions; however, the synchronous stretch condition generated the strongest effect where participants in the low AQ group made estimates closer to the stretched finger as opposed to the location of the actual fingertip. ** The dotted line on the chart indicates the location of the tip of the stretched finger

Figure 4.7 shows a graphical representation of the fingertip estimates made by the respondents during the four conditions. The value of 0 represents that location of the actual fingertip, whereas, the finger was stretched to a total of 2.5 inches (150 pixels). The graph shows that individuals in the baseline condition were closer to the actual fingertip and no significant differences were found between the high and low AQ groups. During the visual stretch condition, there was a significant increase in fingertip estimates compared to the high AQ group. During the Tug condition, there was a significant difference in the fingertip estimate between groups, however, respondents in the high AQ group made judgements closer to their actual finger. In the synchronous stretch condition, respondents in the low AQ group estimated their fingertip to be closer to the stretched image of the index finger (Average estimate score: *2.42, SD: 0.46),* whereas, the average estimation score for the high AQ group remained similar to the previous control conditions. During the baseline condition, both groups made estimations above the '0' mark, this can be attributed to task difficulty as estimating the location of your finger without any visual input can be difficult, which can be seen in figure 4.6 when participants were asked to make estimates regarding their knuckle.

4.4. Discussion

The current study investigated the susceptibility of individuals with high and low self-reported autistic traits to the finger stretching illusion (Newport et al, 2015). The finger stretching illusion was presented to both groups, high AQ and low AQ, alongside a visual stretch and tug condition to further investigate the effects of visual and tactile information, independently. Questionnaire responses collected subjective ratings in relation to ownership and illusion strength in all the conditions, and estimation regarding the perceived location of the fingertip served as an implicit measure of embodiment for which a control condition was adapted where participants were required to estimate the location of metacarpophalangeal joint (first knuckle of the right index finger).

It was predicted that individuals with high and low autistic traits would report high ownership over their digitally presented finger in all conditions, apart from the visual condition where individuals with low autism traits would report lesser ownership over the digitally presented stretched finger. Studies using the MIRAGE system have outlined that typically developing individuals reported lower ownership of their finger just by visually manipulating the digital image (McKenzie & Newport, 2015; Newport et al. 2015; Ratcliffe & Newport, 2017). The results outlined that there were no significant differences found between groups during the baseline condition, where individuals from both groups had high ownership scores. This was expected as no visual or tactile manipulation was applied and the participants viewed their finger in its original form. During the visual stretch condition, there was a drop-in the ownership scores for the low AQ group, as predicted earlier, whereas, the high AQ group had higher ownership scores, similar to the baseline condition. The drop-in ownership scores of the index finger during the visual stretch condition can be, in part, associated with the visual distortion of the image. The visual stretch applied to the video image of the index finger could have altered the perception or the knowledge regarding one's own finger resulting in loss of ownership over the index finger in the low AQ group, as the mental image of finger does not correspond with the current information. Furthermore, this finding, in particular, is consistent with the findings of the previous chapter (please see chapter 2 and 3) in which participants in the low AQ group had lower ownership scores in the experimental condition during which the visual appearance of the right hand was distorted to appear fuzzy or static (crawling skin illusion). Whereas, in the current experiment the finger appeared longer than its usual length. During the tug condition, both groups had high ownership scores, similar to the baseline condition. In the experimental condition, the synchronous stretch condition, both high and low AQ groups had high ownership scores, with no between group differences, as predicted.

Illusion strength ratings were used as a subjective measure of illusion susceptibility; there were no significant differences in the ratings between the two groups during the baseline condition. During the visual stretch condition, there was a significant difference in illusion strength scores, where the low AQ group had significantly lower scores than the high AQ group. However, both groups scored a negative mean score, indicating disagreement with the illusion strength statement but with a variation in the level of disagreement. During the tug condition, there was no difference in illusion strength ratings between groups, where both groups indicated disagreement towards the illusion strength statement. In the synchronous stretch condition, individuals in the low AQ group had a positive illusion strength average indicating strong agreement with the illusion strength statement. However, the high AQ group had a negative average score suggesting disagreement with the statement, reporting lesser effects of the illusion. This difference in illusion strength ratings or susceptibility scores can be attributed to the effectiveness of the finger stretching illusion and has been shown in previous studies using this illusion (Newport et al. 2015). The difference in average illusion strength score between the baseline and synchronous stretch conditions was as predicted, the high AQ group was less affected. This is also consistent with previous research conducted using the rubber hand illusion (Paton et al, 2012) where individuals with higher number of autism traits have scored significantly lower on statements measuring the strength of the illusion during the rubber hand procedure. Differences in ownership over the virtual hand has been used a measure against which illusion strength is compared too; where higher ownership over the hand would increase susceptibility scores (Paton et al, 2012). However, the results of the current investigation do not follow a similar outcome. Individuals with higher number of autism traits had significantly lower scores compared to the low AQ group for the illusion strength ratings while maintaining high ownership over the virtual finger during synchronous stretch (experimental) condition.

Subjective ratings can only provide some information regarding embodiment and ownership; therefore, both groups were required to make implicit judgments regarding the location of the tip of the right index finger in all four conditions. During the baseline condition, there were no differences in estimation scores between the high and low AQ groups, where both groups mean estimates were close to the location of the actual fingertip, however, they were not absolutely accurate. A possible explanation for this could be the fact that in order to comply with the expectations of the experiment, individuals have been shown to slightly overestimate the location of their limbs in previous investigations (Ngeo et al., 2014). Furthermore, estimation errors have been shown to increase when participants are asked to make specific estimations regarding specific joints on the finger (Guerraz et al., 2012; Ngeo et al., 2014). A significant difference was found between groups for the visual stretch condition as evidenced by the increase in the average displacement scores for the low AQ group. During the visual stretch condition, the visual representation of the participant's right index finger was manipulated, where the participant viewed a visual enlargement of the size of the index finger without any tactile input. In virtual reality, discrepancies between the individual's real hand and video hand are reduced, therefore, prior knowledge regarding one's own finger are in favor of the hand being viewed. As opposed to other experimental paradigms, where viewing one's own finger can evoke stronger top- down influences, as the visual appearance of the finger is consistent with the visual representation in the existing internal model (Tsakiris, 2010). Therefore, even though the stretch of the finger was a visual one, it was strong enough for the participants in the low AQ group to overestimate the location of the fingertip, but not as robust, as it was when visual and tactile input were synchronous. Furthermore, Buckingham & Goodale (2010) investigated the role vision plays in perceiving where an object is in the surrounding environment. In their three-part study they asked participants to identify and locate various objects in conditions where vision was present and when the scene was obscured. Interestingly, the investigators reported that whether vision was present or absent, participants over- estimated the location of the objects in order to comply with task expectations (Buckingham & Goodale, 2010).

Similarly, there was a significant difference in displacement scores between groups during the tug condition. As Fig 4.7 shows the High AQ group significantly better at estimating the location of their hidden fingertip compared to the Low AQ group during the tug condition. However, the Low AQ group made lesser displacement errors during the tug condition compared to the visual condition. As this condition was a control condition for the experimental condition, we did not expect to find any displacement errors. One possible explanation for this can be defined by the influence of tactile information. Previously it has been stated that visual information dominates all other senses, (Van Beers et al., 2002; Bebko et al., 2006; Tsakiris, 2010) traditional research indicates that typically both visual and tactile information play a key role in estimating the perceived location of the limb, however, recent research has indicated that tactile sensations only can be sufficient to relocate an individual's sense of perceived location (Van Beers et al., 2002). This suggests that when vision is not present, tactile information alone is sufficient to influence an individual's judgements (Wallwork et al., 2016). Another possible explanation for seeing higher displacement errors in the low AQ group during the tug only condition can be explained in terms of the actual sensation of having one's finger being tugged on (Cappozzo et al., 1995; Dukelow et al., 2010). During this condition the experimenter gently tugs on the participants right index finger during which there is no visual stretch but just the sensation of the finger being pulled after which the vision is blocked. Therefore, when participants are asked to estimate the location of the fingertip, this generates a "localization expectation" which is based on "Prior expectations", which indicates that the simple act of tugging on the finger can influence an individual's estimation skills regarding their own body parts (Brooks & Medina, 2017). Therefore, this could be a potential cause for why we see higher displacement errors from the low AQ group during the tug condition.

The strongest difference was found for the synchronous stretch condition (experimental condition), where the low AQ group estimated the fingertip to be closer to the stretched image, whereas, the high AQ group made judgements closer to the actual fingertip. For individuals with low autism traits, the visuo- tactile synchrony during the synchronous stretch condition generated a strong illusion effect as evidenced by the high illusion strength ratings and estimation scores. This can be the result of the congruency between the visual stretch and pull on the index finger temporarily altering the mental representation of the location of the fingertip, which in turn created a shift in the perceived location of the fingertip. Due to this mental remapping of the perceived location of the fingertip and due to the strong visuo- tactile input the low AQ group estimated the fingertip to be closer to the stretched finger, demonstrating a larger drift (higher errors in estimate task).

However, the average estimation score for the high AQ group was closer to the location of the actual fingertip even in the synchronous stretch condition. This finding indicates that the bottom-up sensory information is not affecting judgements for the high AQ group as it did for the low AQ group. One possible explanation of this could be that the integration of lower- level sensory information with pre- existing cognitive knowledge is not similar to the typically developing population. Previous investigations have provided evidence for the interaction of higher- level cognitive knowledge with lower- level sensory information as being essential for the development of self, body ownership and successful interaction with objects and other people (Botvinick and Cohen, 1998; Tsakiris, 2010; Kilteni et al, 2015). However, the weightage and interpretation of these distinct sources of information varies between individuals. In order to succumb to the finger stretching illusion, individuals must successfully integrate the incoming sensory information with pre- existing cognitive knowledge to experience the illusion. This may be the case for those with lower autism traits, however, for the high AQ group there seems to be a disconnect between the lower- level sensory input and top- down knowledge, which restricts the sensory input to update higher order representations. This failure or inflexibility of top- down processing could explain why the high AQ group is less susceptible to the illusion and were more accurate in estimating the location of the fingertip across all conditions. This is one possible explanation for the data obtained, as these individuals are typically developing adults with traits of autism, therefore, it is important to investigate whether these differences exist in the autistic population as well, therefore, the next study would try to further understand these differences by replicating the current study in individuals with HfA, in order to understand whether these differences are stronger.

Previous studies using sensory illusions have demonstrated that individuals with autism and those with high number of autism traits are less top- down reliant, however, they process bottom- up sensory information but they are selective towards one particular sensory input. In that context, it can be suggested that there seems to be a segregation of information of the illusion at a lower- level, which might allow individuals with high autism traits to discriminate between sensory information focusing on information related to the location of the finger, leading to make more accurate perception of finger location compared to those lower in autism traits (e.g. Cascio et al., 2012; Palmer et al., 2013; Paton et al., 2012). A common finding that is often highlighted during the rubber hand illusion is referred to as proprioceptive drift, where the perceived location of the arm moves away from their real arm and towards the rubber hand (Cascio et al, 2012; Paton et al, 2012; Palmer et al, 2013). Past research suggests similar behavioral and physiological characteristics in individuals with clinically significant traits of autism in the typically developing population and those with a clinical diagnosis of autism, such that their performance on various sensory tasks is very similar (Baron- Cohen et al, 2001a; Happé, 2005; Foss- Feig et al, 2010). The current study served as a baseline to measure behavioral differences in those with high and low autism traits in relation to the finger stretching illusion. Therefore, for the next chapter, I will be further investigating the susceptibility of individuals with a clinical diagnosis of autism and a typically developing comparison group towards the finger stretching illusion. In order to grant a comparison, I will be replicating the current study, employing identical experimental protocols to understand visuo- tactile integration in those individuals with a clinical diagnosis of autism.

Chapter Five

Experiment Four

Susceptibility to a Finger stretching (Visuo, tactile and Proprioceptive) illusion in Individuals with High- Functioning Autism and Typically Developing Adults

5.1. Introduction

Body ownership or identifying a body as one's own is dependent upon the successful integration and interpretation of information from various sensory sources, such as visual, tactile, proprioceptive systems; but they must also be interpreted with respect to top- down knowledge about the body, which modulates perceptual experiences (Tsakiris, 2011). This integrative process of bottom- up sensory information with one's pre- existing (top- down) knowledge is crucial for the development of self and interaction with the environment. Therefore, in order to further explore visuo- tactile and proprioceptive integration in individuals with autism, the finger stretching illusion (Newport et al., 2015) was presented to adults with high- functioning autism.

The finger stretching illusion is a multisensory illusion during which the live video image of a participants own right index finger is visually stretched. Even though the stretch is just a visual one, the synchrony between the visual stretch and tugging of the index finger gives rise to the illusory experience of having one's finger really being stretched. This illusion is extremely compelling as it is presented on the participants own finger and it helps in differentiating the top- down and bottom- up aspects of the illusion itself, where the former is based on the existing knowledge one has regarding their own body part, i.e. their own hand, and the later can be manipulated to present synchronous or asynchronous visuo-tactile information through the manipulation of the current sensory inputs.

Individuals with high- functioning autism (HfA) and a group of typically developing counterparts were subjected to the finger stretching illusion in order to investigate differences in illusion susceptibility and finger ownership. I predict that the synchronous stretch condition (experimental condition) will generate the strongest illusion effect for both groups, especially for the control condition. In terms of ownership, I predict that both groups, HfA and control, would report high ownership scores across all conditions, except for the visual stretch condition, for which the control group will report lower ownership ratings. This is based on the results of the previous investigation during which participants with high and low autism traits (Chapter 4) reported lower ownership over their digitally presented finger due to visual manipulation. Furthermore, this predication is also made on the basis of the outcome of a study conducted by Tsakiris (2011) where it was suggested that visual manipulation of an individual's body parts automatically leads an individual to lose ownership over their manipulated body part and this is the result of mental mismatching whereby the current visual input does not match with that of their mental schema. In terms of illusion susceptibility, I predict that the control group would report higher susceptibility scores during the synchronous stretch condition (experimental condition) compared to the autistic group. This is in line with the findings of the investigation conducted by Greenfield et al., (2015) where the children and adults with autism were less susceptible towards an illusion presented through the MIRAGE during which the participants were required to identify their real hand from two virtual hands while the experimenter presented both visual and tactile information on a virtual hand. The visual stretch and tug conditions would not generate positive illusion strength ratings for both groups. For the judgement task, only the synchronous stretch condition should generate an effect where the perceived location of the fingertip would substantially drift towards the location of the stretched fingertip. I predict that individuals in the control group would be more influenced by the visual- tactile inputs and make judgments close to the location of the stretched tip as this prediction is based on the results gathered by an investigation conducted by Newport et al. (2015) where adults of typical development where highly influenced by the synchrony of the visual and tactile inputs presented over their right fingertip where they estimated the location of their finger to be closer to the location of the stretched finger. As for the autistic group, based on the results of the previous investigation (chapter 4), this group will be less influenced by the visuo- tactile synchrony, hence, making judgements closer to the actual fingertip. Furthermore, this prediction is also based on the premise that individuals with autism tend to be more accurate in tasks requiring them to estimate the location of their hand (Greenfield et al, 2015) and their own body parts (Moy et al., 2007; Steele & Bramblett., 1988; Smith et al., 2010). Also, existing literature (Blanche et al., 2012; Izawa et al., 2012; Schauder et al., 2015a) indicates that individuals with autism tend to rely more on bottom- up sensory sources, i.e. proprioception, rather than integrating sensory inputs with their existing knowledge, therefore, it is predicted that during the judgment task the autistic group will be more accurate in locating their fingertip, as previous studies (Paton et al., 2012; Palmer et al., 2013; Cascio et al., 2010; Stenneken et al., 2006; Sarlengna & Sainburg, 2009) have indicated that individuals with autism tend to rely on proprioception, hence, enabling them to be better at estimation tasks. As a control measure, participants were required to make judgments regarding the location of their right knuckle. This condition did not involve any manipulation or treatment as the illusion only deals with the fingertip.

[12]5.2. Method

5.2.1 Design

A mixed design was used with group being the between subjects-factor (HfA vs TD participants) and condition being the within-subject factor (Baseline vs Visual Stretch vs Tug vs Synchronous stretch conditions), and the dependent variables being ownership ratings, illusion Susceptibility ratings and finger estimation scores

5.2.2. Participants

A total of thirty participants were recruited for the current investigation. This consisted of fifteen right handed adults (8 males and 7 females) with high functioning autism (HfA) aged between eighteen to twenty-eight years of age (Mean age = 22.2 years, SD = 2.62) and a comparison group of fifteen (9 females and 6 males) age matched typically developing adults (Mean age = 22.0 years, SD = 2.91). It is important to note that the participants of this study were the same group of people who took part in Chapter 3 (experiment 2).

The status of the clinical group as “high- functioning” was reconfirmed by their performance on a standardized cognitive assessment, Wechsler Adult Intelligence Scale – fourth edition (WAIS-IV). Groups were matched on the overall Intelligence scores, where there

[12] The experimental procedure and the conditions of this current study were exactly identical as the previous study (experiment number 3). The only difference was the change in the population studied.

was no significant difference found between the full-scale IQ of the HfA and comparison group, t (2, 28) = - .168, p = .868 (*check table 5.1 for participant demographics*). *(Please see Chapter 3, Section 3.2 for a detailed description of the participants)*

Group (Sample Size)	Statistic	Age (Years)	Autistic Quotient (AQ)	ADOS-II Total (communication + social interaction)	Verbal IQ (VIQ)	Performance IQ (PIQ)	Full-Scale IQ (FSIQ)
HfA	Mean	22.2	40.7	10.87	101.73	110.87	106.73
(15)	SD	2.62	4.35	2.92	17.49	14.74	15.08
	Range	*18 - 27*	*32 – 46*	*7 - 17*	*66 -127*	*72 - 125*	*75 - 125*
Controls	Mean	22.0	13.5	-	101.67	112.47	107.53
(15)	SD	2.91	6.83	-	12.90	12.34	10.7
	Range	*18 - 28*	*3 - 27*	-	*87 - 128*	*90 - 127*	*87 - 123*

Table 5.1 Displays the participant characteristics for the High- functioning autistic group and typically developing control group

5.2.3 Materials

5.2.3a. Experimental conditions and MIRAGE system

The Finger stretching illusion (Newport et al., 2015) was presented to the participants, along with a baseline condition and two control conditions. All participants were presented with the baseline condition first to minimize the illusion carry- over effects. As a control for the fingertip estimation task, participants were required to make judgments regarding the knuckle, which served as a control for the fingertip estimation.

Questionnaires Data

The same illusion ownership questionnaire from Chapter 4 was used, it consisted of three statements in total: (i) an ownership statement to assess experience of finger ownership during the experiment, (ii) illusion strength statement that was used to measure illusion susceptibility and (iii) a control statement that was used as an attention filter (Table 5.2 shows the statements used during the MIRAGE investigation). Participants made verbal judgements on a 7.0 rating scale for which -3 indicated strong disagreements, 0 denoted neutral and 3 indicated strong agreement with the statement. All statements were presented to participants in a random order, counter balanced between each participant and condition.

Item Type	Text (Statement)
Ownership	The finger that I see is a part of my body
Illusion Strength	It felt like my finger was really being stretched
Control	My finger feels warmer than usual

Table 5.2 Statements used to measure finger ownership and illusion susceptibility of respondents across all conditions during the MIRAGE investigation

Objective Data

As an implicit measure of illusion ownership and susceptibility, participants were required to make estimations in each of the conditions. This was completed after they had rated the illusion experience questionnaire.

5.2.3b. Experimental Procedure

Participants sat on a chair in front of the MIRAGE, ensuring that they could view their right hand when they placed it onto the work surface of the MIRAGE device. A rectangular black bib attached across the length of the MIRAGE was tied comfortably around the participant's shoulders to obscure a direct view of their upper arm. Participants rated the illusion experience questionnaire after which they made judgements of regarding the fingertip and the knuckle of index finger. Following the baseline condition, participants were presented with the rest of the conditions and in each condition, they were required to rate the illusion experience questionnaire and make estimates regarding the fingertip and the knuckle of the index finger. All conditions were counterbalanced between participants; however, the baseline condition was always presented first in order to minimize any carry over effects. During each condition, participants made estimation of the fingertip twice, from top to bottom and then from bottom to top. Following the knuckle estimate, this was done in a similar way. The order in which participants made judgements was also counterbalanced between participants (Please see Chapter 4, Section 4.2.3 for a detailed explanation for the experimental procedure).

5.3. Results

Subjective ratings were collected using an illusion ownership questionnaire. Objective data was collected through judgements regarding the location of the index finger in each of the conditions after the image was manipulated. As a control measure for the fingertip estimation, participants were required to make estimations regarding their knuckle, as the illusion should not have any effects on the participant's knowledge regarding the knuckle. For each set of data, it was analyzed using a 4 *(Conditions: Baseline Vs Visual Stretch Vs Tug Vs Synchronous Stretch)* x 2 *(Groups: HfA vs Controls)* Repeated Measures ANOVA with conditions as the within- items factor and groups as the between- subjects factor. Pairwise comparisons

(Bonferroni- corrected) were used to assess any main effects and independent samples t- tests (Bonferroni- corrected) were computed to test any significant interactions.

5.3.1. Subjective Ratings

Ratings were made on a -3 to 3 rating scale, where -3 denoted disagreement and 3 referred to strong agreement with the statements.

Control Statements

Respondents' ratings for the control statement "my hand feels warmer than usual" were analyzed using a Repeated Measures ANOVA. A 4 (conditions) x 2 (groups) ANOVA revealed no significant main effect of condition, $F\ (2, 28) = 1.68, p = .177\ (\eta^2 = .057)$. There was also no significant interaction reported between groups and conditions, $F\ (2, 28) = .826, p = .476\ (\eta^2 = .029$, *indicating* that there were no significant differences between the ratings given for the control statement by HfA and Control groups.

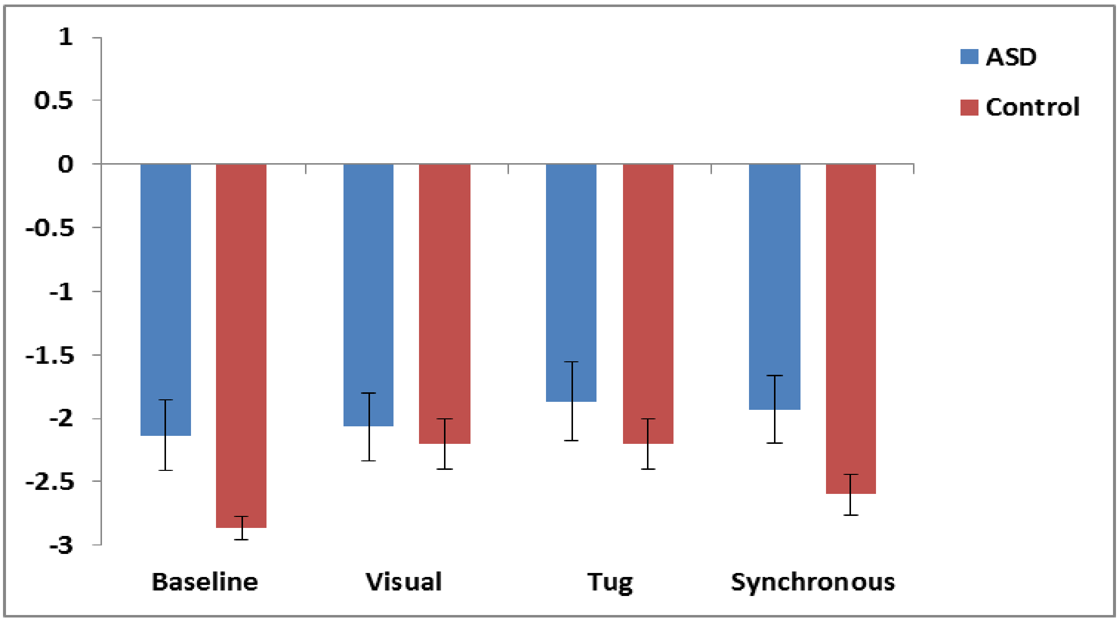


Fig 5.1 Graphical representation of subjective ratings given for the statement "my hand feels warmer than usual" which was used as a control statement. No significant differences were found between the ASD and control groups across conditions as both groups disagreed with control statement (as indicated by the negative ratings).

Illusion Ownership Ratings

In order to examine the differences in ownership felt over the finger during the various conditions, ratings to the ownership statement *"the finger that I see is a part of my body"* were used as a mean ownership score for each participant. A 4 x 2 Repeated Measures ANOVA revealed a significant main effect of condition, $F\ (2,\ 28) = 40.25,\ p < .001\ (\eta^2 = .590)$ indicating differences in ownership ratings. Pairwise comparisons (Bonferroni- corrected) revealed a significant difference in ownership rating during the baseline and visual stretch conditions, $p < .001$, $(\eta^2 = 1.015)$, suggesting that groups reported higher ownership during the baseline condition *(Mean: 2.76, SD: 0.78)* compared to the visual stretch condition *(Mean: - 0.67, SD: .32)*. There was also a significant difference in ownership ratings between the visual stretch and tug condition, $p < .001$, (η^2 = - .951), indicating that ownership ratings were higher for the tug condition *(Mean = 2.33, SD = .19)* compared to the visual stretch condition *(Mean = -. 67, SD = .32)*. There was no difference in ownership ratings between the tug and synchronous stretch conditions, $p = 1.00$, (η^2 = .501), indicating that ownership ratings for the tug condition *(Mean = 2.33, SD = .19)* were not significantly different from the synchronous stretch condition *(Mean = 1.97, SD = .21)*. There was also a significant difference in ownership ratings between the synchronous stretch condition and baseline condition, $p < .001$, (η^2 = .823), indicating that ownership ratings were higher during the baseline condition *(Mean = 2.76, SD = 0.78)* compared to the synchronous stretch condition *(Mean = 1.97, SD = .21)*. There was also a significant difference in ownership ratings during the visual stretch and synchronous stretch conditions, $p = .043$, (η^2 = - .363), indicating that ownership scores were lower for the visual stretch condition *(Mean = - .67, SD = .19)* compared to the synchronous stretch condition *(Mean = 1.97, SD = .21)*. However, there were no significant differences in ownership ratings during the tug and baseline conditions, $p = .262$ (η^2 = - .424), indicating that scores during the baseline condition *(Mean = 2.76. SD = 0.78)* did not differ from the tug condition *(Mean = 2.33, SD = .19)*.

More importantly, there was a significant interaction between conditions and groups, $F(2, 28) = 14.45$, $p < .001$ (η^2 = .340). Post hoc independent samples t- tests (Bonferroni-corrected) revealed no significant differences in ownership scores between the HfA group and control group, $t(2,28) = -1.28$, $p = .208$, (η^2 = .282). A significant difference in ownership ratings was found between groups during the visual stretch condition, $t(2, 28) = 4.20$, $p < .001$

$(\eta^2 = .454)$, suggesting that respondents in the HfA group had higher ownership ratings *(Mean = 1.27, SD = 1.62)* compared to the control group *(Mean = - 1.40, SD = 1.84)*. There were no significant differences in ownership ratings between groups during the tug condition, $t\ (2, 28) = -.350,\ p = .729,\ (\eta^2 = .581)$. Similarly, no significant differences in ownership ratings were found between the HfA and control group during the synchronous stretch condition, $t\ (2, 28) = -1.41,\ p = .171,\ (\eta^2 = .795)$.

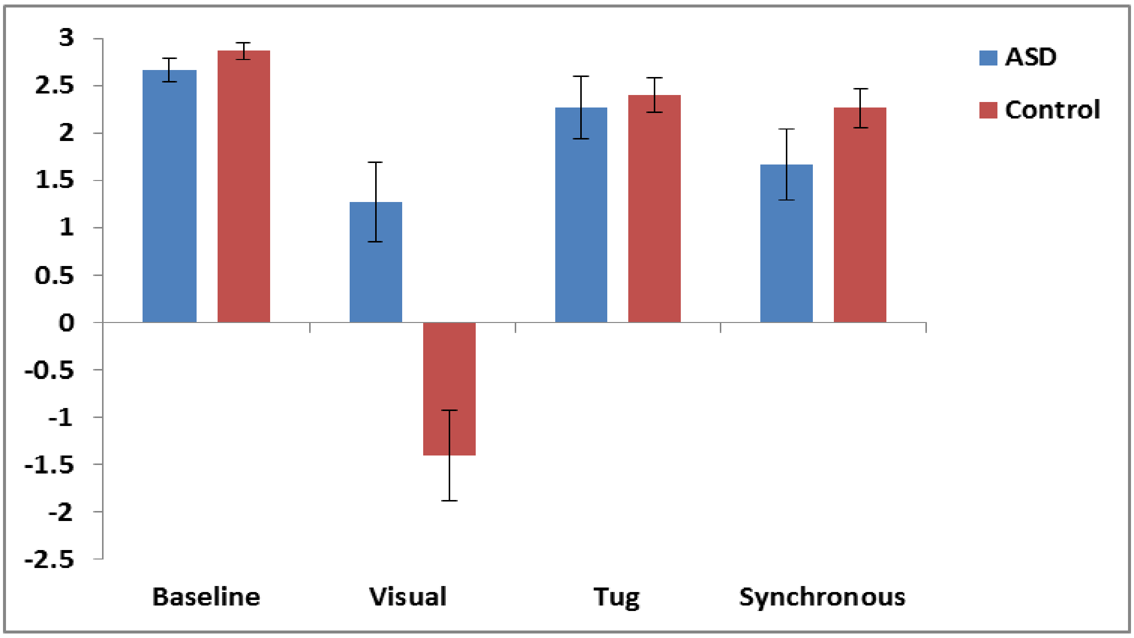


Fig 5.2 Mean Ownership Ratings for the ASD (red bars) and control (blue bars) groups across all conditions. The bar chart indicates no significant difference in ownership ratings between groups during the baseline condition and tug condition. A significant difference was found for the visual condition. No significant difference was found for the synchronous stretch condition.

Illusion Strength Ratings

Illusion strength ratings were used as a subjective measure to total the level of susceptibility participants felt over their finger in each of the conditions. Ratings to illusion strength statement “it felt like my finger was really being stretched” were used as a mean susceptibility score for each of the participant. Repeated Measures ANOVA revealed a main effect of condition, $F(2, 28) = 152.55, p < .001$ ($\eta^2 = .845$) indicating differences in illusion strength ratings. Pairwise comparisons (Bonferroni- corrected) revealed a significant difference in illusion strength ratings between baseline and visual stretch conditions, $p = .002$, ($\eta^2 = - .917$), indicating that respondents gave lower illusion strength ratings during the baseline condition *(Mean = - 2.76, SD = .078)* compared to visual stretch condition *(Mean = - 2.23, SD = .151)*. There were no significant differences in illusion strength ratings between the visual stretch and tug condition, $p = .230$, ($\eta^2 = - .518$), indicating that illusion strength scores were similar during the visual stretch condition *(Mean = -2.23, SD = .151)* and the tug condition *(Mean = - 1.60, SD = .25)*. There was a significant difference in illusion strength ratings between the tug and synchronous stretch conditions, $p < .001$, ($\eta^2 = - .242$), indicating that susceptibility scores were higher during the synchronous stretch condition *(Mean = 1.77, SD = .173)* compared to the tug condition *(Mean = - 1.60, SD = .25)*. A significant difference in illusion strength scores was sound between the synchronous stretch condition and baseline condition, $p < .001$, ($\eta^2 = - .387$), indicating that susceptibility scores were higher during the synchronous stretch condition *(Mean = 1.77, SD = .173)* compared to the baseline condition *(Mean = - 2.76, SD: .078)*. There was also a significant difference in illusion strength ratings between the tug and baseline conditions, $p < .001$, ($\eta^2 = 1.477$), indicating that lowest susceptibility scores were found for the baseline condition *(Mean = - 2.76, SD = .078)* compared to tug condition *(Mean = - 1.60, SD = .25)*. Furthermore, a significant difference in susceptibility scores was found between the visual stretch condition and synchronous stretch conditions, *p < .001, (*η^2 *= -.941)*, indicating that higher susceptibility scores were found for the synchronous stretch condition *(Mean = 1.77, SD = .173)* compared to the visual stretch condition *(Mean = - 2.23, SD = .151).*

There was also a significant interaction between groups and conditions, *F (2, 28) = 12.23, p < .001 (*η^2 *= .304).* Four independent samples post hoc t- tests (Bonferroni- corrected) were conducted to test differences in ratings between groups during each condition. They revealed no significant differences in illusion strength ratings between groups during the baseline condition*, t (2, 28) = 1.28, p = .208, (*η^2 *= -.542)*, indicating that the HfA group *(Mean = - 2.67, SD = .48)* and the control group *(Mean = - 2.87, SD = .35)* scored similarly during the Baseline condition. Both groups had an average negative score indicating disagreement with the illusion strength statement, reporting lower susceptibility. There was no significant difference between groups during the visual stretch condition*, t (2, 28) = .664, p =. 512, (*η^2 *= - .440)*, suggesting that there were no differences in illusion strength ratings between the HfA *(Mean = - 2.33, SD = .89)* and control group *(Mean = - 2.13, SD = .74)* during the visual stretch condition. No differences were found between groups during the tug condition*, t (2, 28) = 1.86, p = 0.073, (*η^2 *= .671)*, indicating that the HfA group *(Mean = - 1.13, SD = 1.84)* and control group (*Mean = - 2.06, SD = .59)* during the tug condition. However, there was significant difference in susceptibility ratings between groups during the synchronous stretch condition*, t (2, 28) – 5.21, p < .001, (*η^2 *= - .883),* suggesting that the control group *(Mean = 2.67, SD = .48)* reported higher susceptibility compared to the HfA group *(Mean = .867, SD = 1.24)* during the synchronous stretch condition.

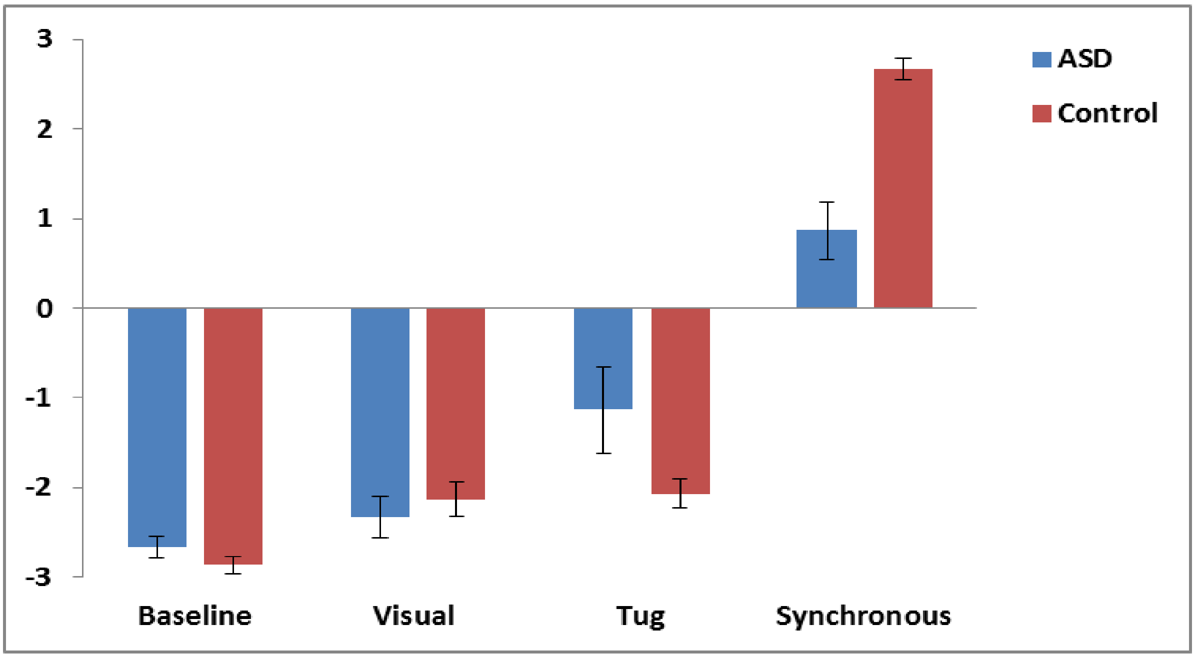


Fig 5.3 Mean illusion strength Ratings for the ASD (red bars) and control (blue bars) groups across all conditions. The bar chart indicates a significant difference in strength ratings during the baseline condition, tug condition and synchronous stretch conditions. No significant difference in illusion strength ratings was found for the visual stretch condition.

Objective Measures

After each condition, participants were required to make judgements regarding the location of the right index finger. This was completed immediately after participants rated the illusion experience questionnaire. A black screen overlaid the screen that displayed the participants' hand, after which a red horizontal line would move vertically starting either from the top or the bottom of the screen. In either case, participants made two judgements, one when the red line moved from the top and the second one when the line appeared from the bottom of the screen. As a control measure, participants made estimates regarding the location of the knuckle of the index finger.

Data collected regarding the fingertip and knuckle estimate was in pixels. Values for each participant, in pixels, were than subtracted from the location of the real fingertip. The difference between the estimate and the real fingertip was then converted into inches; after which SPSS was used to further analyze the data. For example, all participants real fingertip was always placed at 300 pixels after which the finger was visually stretched to a total of 150 pixels, so the participant would view their finger to the 450-pixel point. When making the estimate, participant would have to make judgements regarding the actual fingertip. Later, when the data was analyzed, the original location of the fingertip was considered as a '0' and the point of the visually stretched finger was denoted as 2.5 inches *(150 pixels from the original point*).

Knuckle Estimation (control)

As a control for the fingertip estimates, participants were required to make judgements regarding the knuckle of the index finger. As the illusion is finger specific, the estimate of the knuckle was used as a control measure because this would not have been affected. A 2 (groups) x 4 (conditions) Repeated Measures ANOVA revealed a significant main effect of condition, $F\ (2, 28) = 3.829,\ p = .024\ (\eta^2 = .203)$, indicating variances in knuckle estimation between conditions. Pairwise comparisons (Bonferroni- Corrected) revealed no significant difference in knuckle estimation scores during the baseline and visual condition, $p = 1.00\ (\eta^2 = .323)$. No significant difference in knuckle estimation was found for the visual stretch and tug conditions, $p = 0.898,\ (\eta^2 = .588)$. No significant difference was found between the tug and synchronous stretch conditions, $p = 1.00,\ (\eta^2 = .486)$. There was a significant difference in knuckle estimation score between the baseline and tug condition, $p = .008$, ($\eta^2 = .443$), indicating that knuckle estimates were closer to "0" during the baseline condition *(Mean = .092, SD = .013)* compared to the tug condition *(Mean = .148, SD = .011)*. There was also a significant difference in knuckle estimates during the baseline and synchronous stretch conditions, $p = .002$, ($\eta^2 = .699$), indicating that estimates were lower during the baseline condition *(Mean = .092, SD = .013)* compared to the synchronous stretch condition *(Mean = .167, SD = .014)*. However, there was no significant difference in estimation scores between the visual stretch and synchronous stretch conditions, $p = .191$, ($\eta^2 = .250$).

Repeated Measures ANOVA revealed no significant interaction between groups and conditions for the knuckle estimation scores, F (2, 28) = .779, p = .474 ($\eta^2 = 0.012$). (Fig 5.4).

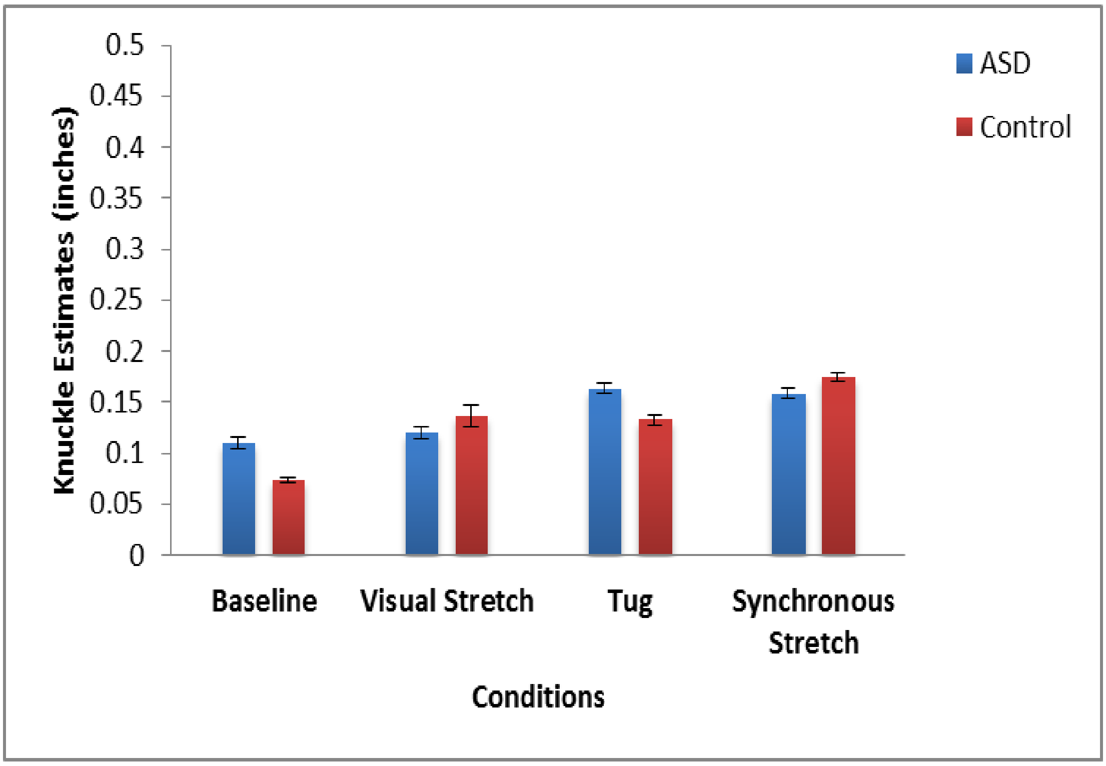


Fig 5.4 Average Knuckle estimation scores for the ASD group (red bars) and the control group (blue bars) across all conditions. The bar chart indicates no significant difference between groups across all conditions.

Fingertip Estimates

A 2 (Groups: HfA vs Control) x 4 (Conditions: Baseline vs Visual vs Tug vs Synchronous Stretch) Mixed ANOVA revealed a significant main effect of conditions, $F(2, 28) = 68.191, p < .001$ ($\eta^2 = .709$), indicating a difference in estimates of the fingertip between conditions. Pairwise comparisons (Bonferroni- corrected) revealed a significant difference in fingertip estimation between the baseline and visual conditions, $p < .001$, ($\eta^2 = .898$), indicating that during the baseline condition *(Mean = .279 inches, SD = .033)* fingertip estimate was closer to the actual location of the finger compared to the visual condition (*Mean = .982, SD = .053)*. A significant difference was found between the visual stretch and tug conditions, $p < .001$, ($\eta^2 = .286$), indicating that the estimation scores were closer to the fingertip during the tug condition (*Mean = .537, SD = .062*) compared to the visual stretch condition *(Mean = .982, SD = .053*). There was also a significant difference in estimation scores during the tug and synchronous stretch conditions, $p < .001$, ($\eta^2 = .283$), indicating that overall estimation scores were closer to the actual fingertip during the tug condition *(Mean = .537, SD = .062)* compared to the synchronous stretch condition *(Mean = 1.34, SD = .061)*. Furthermore, there was also a significant difference in estimation scores between the baseline and synchronous stretch conditions, $p < .001$, ($\eta^2 = .914$), indicating that fingertip estimation was closer to the actual finger during the baseline condition *(Mean = .274, SD = .033)* compared to the synchronous stretch condition *(Mean = 1.34, SD = .061)*. There was also a significant difference in estimation scores between the tug and baseline conditions, $p = .015$, ($\eta^2 = .369$), suggesting that estimates were more accurate during the baseline condition *(Mean*

= .274, SD = .033) compared to the tug condition *(Mean = .537, SD = .062)*. Finally, there was also a significant difference in estimation scores between the visual and synchronous conditions, $p < .001$, *(*$\eta^2 = .583$*)*, indicating that estimates were closer to the actual finger during the visual condition *(Mean = .982, SD = .053)* compared to the synchronous stretch condition *(Mean = 1.34, SD = .061)*.

The results also revealed a significant interaction between groups and conditions, $F(2, 28) = 68.186$, $p < .001$ ($\eta^2 = .709$). Post Hoc independent sample t- tests (Bonferroni-corrected) revealed a significant difference in estimation scores between the HfA and control group during the baseline condition, $t(2, 28) = -2.779$, $p = .010$, ($\eta^2 = .522$), indicating that the HfA group *(Mean = .181, SD = .128)* made estimates closer to the actual fingertip during the baseline condition compared to the control group *(Mean = .367, SD = .224)*. During the visual stretch condition, there was a significant difference in estimation scores between the HfA and control group, $t(2, 28) = -15.150$, $p < .001$, ($\eta^2 = .617$), indicating that the ASD group *(Mean = .178, SD = .049)* had estimates closer to the actual fingertip compared to the control group *(Mean = 1.787, SD = .408)* during the visual stretch condition. There was also a significant difference in estimation scores during between groups during the tug condition, $t(2, 28) = -3.366$, $p = 0.02$, ($\eta^2 = .431$), indicating that the HfA group *(Mean = .330, SD = .270)* made estimates closer to the actual fingertip compared to the control group *(Mean = .745, SD = .393)* during the tug condition. Finally, there was also a significant difference in estimation scores between groups during the synchronous stretch condition, $t(2, 28) = -17.65$, $p < .001$, ($\eta^2 = .737$), indicating that the HfA group *(Mean = .263, SD = .143)* made estimations of the fingertip closer to the actual location of the finger compared to the control group *(Mean = 2.412, SD = .449)* whose estimates were closer to the location of the visually stretched finger during the synchronous stretch condition.

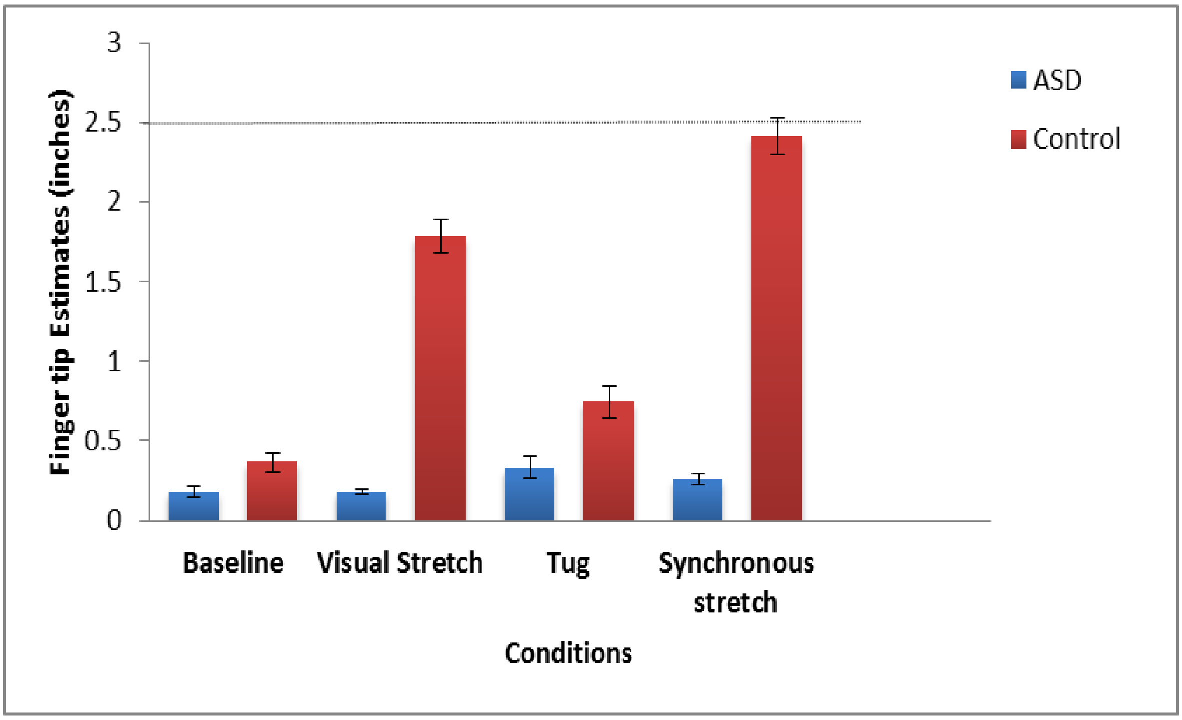


Fig 5.6 Mean estimations cores for the ASD group (blue bars) and control group (red bars) across all conditions. The bar chart indicates significant differences in estimation scores across all conditions. The ASD group estimation scores were all close to “0” indicating judgements closer to the location of the actual fingertip. Estimates closer to the dotted line on the chart indicates the location of the tip of the visually stretched finger.

Discussion

The current study investigated the susceptibility of individuals with high- functioning autism (HfA) and typical developed matched controls towards the finger stretching illusion (Newport et al, 2015). The finger stretching illusion was presented to both groups, along with a visual stretch and tug condition, which served as control conditions and to investigate the effects of visual and tactile inputs, independently. An illusion ownership and strength questionnaire were used to collect subjective ratings and an estimation regarding the perceived location of the actual fingertip, in all conditions, was used as an implicit measure of embodiment of the illusion.

It was predicted that individuals from both groups would report high ownership over the digitally presented finger during the baseline condition, however, the control group would show variance in ownership across the other three conditions. This was based on the results gathered from the previous investigation and the results gathered from Newport et al., (2015) investigation. However, the results outlined no significant differences between groups during the baseline condition, tug condition and the synchronous stretch conditions. However, there was a significant difference in ownership ratings during the visual stretch condition, during which participants in the control group gave negative ratings towards the ownership statement. The loss of ownership during the visual stretch condition can be associated with the visual distortion of the image, altering the perception of one's own finger. These results are consistent with the outcome of the previous study, during which individuals with low autism traits reported negative ownership over the visually stretched finger. However, this difference was more pronounced between the control and HfA participants. According to Tsakiris (2010) visual distortion on its own is sufficient to alter one's perception of their own body part and this is due to the weightage given to visual input as opposed to other sensory sources. Therefore, for the control group, the visual distortion in the appearance of the fingertip seems to be sufficient to influence their judgements regarding their own body part (Tsakiris & Haggard, 2005; Tsakiris, 2011), as it no longer looks like their finger, they disown it as their own.

In terms of illusion strength ratings, it was predicted that participants would report higher (positive) ratings for the illusion strength statement during the synchronous stretch condition (experimental condition) as this condition has been shown to generate high susceptibility ratings in past research (Newport & Giplin, 2011; Newport et al., 2015). The results support this prediction, as there was no between group differences found for the illusion strength ratings during the baseline and visual stretch conditions, where both groups gave negative ratings for the statement assessing susceptibility to the illusion. A between group difference was found for the illusion strength ratings during the tug condition, however, even though the ratings were within the negative range, both groups disagreed with the susceptibility statement during the tug condition, where the HfA group displayed lesser disagreement compared to the control participants. The HfA group reporting lesser disagreement during the tug condition can be due to the wording of the statement used. As previous research has already established that individuals with HfA tend to present a rigid cognitive style (Fitch et al., 2015; Happé et al., 2006a), therefore, it could be due to the way the statement was interpreted by the HfA group. This shows that the wording of a question could alter the results of questionnaires when testing the autistic population. The synchronous stretch condition was predicted to produce the strongest susceptibility scores. The results outline a significant difference in illusion strength ratings between groups, where the control group had much higher ratings compared to the HfA group. However, according to the results, they do show an agreement with the susceptibility scores indicating that they are potentially susceptible towards the illusion. Therefore, in order to further explore whether this difference is due to demand characteristics or whether an actual fact, objective measures where employed to investigate this further.

As a more concrete measure of ownership, participants in both groups were required to make implicit judgements regarding the location of the tip of the right index finger in each condition. Based on the results from the previous investigation with individuals with high and low autism traits, I predicted a similar pattern in estimation, as this estimation task was introduced for the first time using this illusion, it was difficult to predict the exact pattern of performance. There were significant differences in estimation scores, between groups, during the baseline condition, where the HfA group made estimates closer to the location of the actual fingertip. During the visual stretch condition, a significant difference was found between groups, where the control group's estimations scores were closer to the location of the digitally stretched finger, compared to the HfA group. During the visual stretch condition, the visual representation of the participants finger is visually stretched without any tactile input. The visual enlargement of the limb has been shown previously to alter a participants judgements regarding their own hands in relation to size and location; whereby studies have shown that participants are more inclined to report their own body part as not their own (Nico et al., 2004; Apker et al., 2011; Guerraz et al., 2012; Ngeo et al., 2014). Therefore, in the present study, the visual context, i.e. enlargement of the finger, seems sufficient to alter a participant's judgments regarding their own finger indicating the instantaneous integration of the visual input and existing cognitive knowledge regarding their own body part. This highlights the typical integration that has been shown using sensory illusions such as the Shepard's illusion, Müller-lyer illusion and the Ponzo illusion where individuals are susceptible to the illusion due to the rapid integration of visual information with top- down knowledge (Ropar & Mitchell, 2001; McCauley & Henrich, 2006). Furthermore, this provides us with support that not only does this process occur with 2- dimensional static stimuli but it can also be applied to an individual's own limbs. Similarly, there was a significant difference in estimation scores during the tug condition, during which, the HfA group made judgements closer to the actual fingertip, compared to the control group whose judgements were higher than the HfA group but lower than their own estimations during the visual condition. A possible explanation for this is that tactile sensations only can be sufficient to relocate an individual's sense of perceived limb location (Van Beers et al., 2002). This indicates that when vision is absent tactile information is sufficient to influence a person judgements regarding their own hand (Wallwork et al., 2016). Unlike previous investigations, i.e. such as the RHI, the mannequin illusion and the full body illusion, where the effect of isolated senses hasn't been studied, this could potentially be the basis of investigating the effects of tactile stimulation in relation to body ownership and perceived limb locations.

The synchronous stretch condition was predicted to have the strongest illusion effect in regards to finger estimation for the control group. The results of this investigation were in favor of this prediction, as the strongest difference was found for the synchronous stretch condition, where participants in the control group estimated the fingertip to be closer to the stretched image, whereas, the HfA group estimates were closer to the location of the actual finger. This finding is a novel finding as previous investigations that have used tasks during which individuals with autism are required to estimate the location of their arm (Cascio et al., 2012; Paton et al, 2012; Palmer et al., 2013) have based their findings mostly on the subjective data collected, i.e. susceptibility ratings. However, subjective ratings are prone to biases, whereas, a judgment task provides a more concrete measure of embodiment. Therefore, it can be suggested that individuals with autism do not tend to embody the illusion and this could be due to a higher reliance on a single sensory source, i.e. proprioception, while over- riding the visual and tactile information.

The knuckle estimates were used as a control for the fingertip estimation task as the illusion does not involve changes in the estimations made regarding the knuckle. However, the results of the knuckle estimates show a variation in judgments between groups. This can be associated with task difficulty. Another interpretation of variations in the knuckle estimations could be explained under the idea of "expectance". As the finger stretching illusion is a very compelling illusion, the extension of the finger could have influenced the participants judgements regarding the knuckle i.e. if the finger is getting longer than the location of the knuckle should move as well. However, this is a novel finding and it indicates that extension of the finger is not limited to the finger itself, but can have an effect on the other connecting parts of the limb or a mere sign of task difficulty. This provides us with knowledge that the finger stretching illusion might not just be limited to the finger, whereas, it can impact the closer joints as well.

The distinction between the bottom- up sensory inputs and top- down information are very clear in the finger stretching illusion. The correlation between the visual and tactile inputs facilitate the experience of ownership of a "stretched finger" and also modulates proprioception, where individuals who succumb to the illusion estimate the fingertip to be closer to the "stretched tip" (Newport & Giplin, 2011; Newport et al., 2015). The results of the current investigation support this idea, but only for individuals of typical development. The synchrony between the viewing of the visual stretch alongside the tug on the tip of the right index finger is sufficient to influence the judgment regarding the location of the fingertip for the typically developing control group. However, the visual and tactile inputs are not influencing the judgement regarding the fingertip for the HfA group indicating that at a sensory level they are not integrating the visual- tactile information or it could be suggested that they have a more rigid body ownership schema. This result can be viewed and compared to the previous results gathered using the rubber hand illusion, where individuals with ASD are more reliant on proprioception as oppose to the bottom- up sensory information (Paton et al., 2012; Palmer et al., 2013)., which further clarifies our findings. Such that, during the RHI participants are required to reach for location of where they think their right hand is and their estimations are closer to their own hidden hand rather than the fake rubber hand. Similarly, in the present investigation, the HfA group made estimates closer to their own fingertip rather than estimating it to be closer to where they saw their finger was. Therefore, overriding visuo- tactile stimulation.

Past research using sensory illusions has suggested that individuals with autism are less influenced by the bottom- up sensory information (Firth and Happé 1994; Happé and Firth 1996; Behrmann et al., 2006; Happé and Booth, 2008), whereby, they process information in a very selective manner. For the typical developing population, the successful integration of individual information from visual and tactile inputs seems to modulate the experience of the illusion, such that viewing the finger being stretched and feeling that it is being tugged is sufficient enough to relocate the position of their own finger, however, this is not the case for those with autism who do not integrate the visual and tactile inputs required to experience the illusion. However, they seem to discriminate between sensory information focusing on information related to the location of the fingertip, which can translate into "drift", which is another common finding often reported when individuals with autism experience the rubber hand illusion.

The Rubber hand illusion (RHI) has been widely studied in the autistic population, where the results gathered from these various studies have indicated that individuals with autism tend to report low susceptibility in illusion strength ratings, however, show superior performance in estimating the location of their hidden hand (Cascio et al., 2013; Paton et al., 2012; Palmer et al., 2013, Cascio et al., 2020). This superior performance has been suggested by these investigators as heightened proprioceptive performance in the autistic population. Studies that have used the RHI paradigm have reported that children and adults with autism tend to estimate their hand to be closer to their real hidden hand rather than the fake rubber hand. Opponents of the RHI paradigm argue that differences in performance are due to the failure of individuals with autism to incorporate "a fake hand" and believe it to be their own due to their rigid thinking styles and extreme attention to detail (O'Neil & Jones., 1997; Mottron et al., 2006).

This would mean that individuals with autism pay extra attention to details which could possibly hinder them from accepting an artificial object as their own. Keeping in line with this idea, the current study used virtual reality to present an illusion on the participants own right finger in order to present a more realistic illusion on the participants own hand. The results indicated that HfA participants did in fact made estimates closer to their real finger rather than where they saw their finger was after the synchronous visual and tactile inputs.

The results gathered during this investigation alongside past research using the RHI (Paton et al., 2012) indicates that individuals with autism and those with high autism traits (Chapter 4) display a heightened reliance on proprioception as opposed to individuals of typical development for which visuo- tactile correlations modulate proprioception. This idea of over-relying on proprioception has become a very rapidly studied area in autism as proprioception is a significant sensory source but often overlooked. Therefore, in the context of the findings of this research so far, it seems as though vision and proprioception are producing the strongest effect, but the tactile input is only modulating the illusion effect on those of typical development with low autism traits. Furthermore, previous investigations measuring visuo-proprioceptive integration have shown that both children and adults are better at hand localization tasks when both visual and proprioceptive information are congruent and available (Nardini et al., 2008). Nardini and colleagues (2008) suggested that estimations are much more accurate when both sensory sources are available, however, when visual and proprioceptive inputs are incongruent, participants estimate were based on a model of optimal integration, such that their judgements relied on a weighted average of both the sensory sources. This model of optimal integration has been studied widely but mostly in individuals of typical development (Nardini et al., 2013). In relation to the data gathered so far in this research, it shows that optimal integration is only taking place for individuals of typical development, whereas, those with high autism traits and HfA tend to prefer a singular sensory source over the other, which in this case is proprioception. Therefore, in order to investigate this further, this research will further investigate visuo- proprioceptive integration in individuals with high and low autism traits. With the use of the MIRAGE system (Newport & Gilpin, 2011), I will be presenting participants with an illusion that only manipulates visual and proprioceptive information to further understand the reliance on proprioception in individuals with high and low autism traits and those with a clinical diagnosis of autism

Chapter Six

Experiment Five

Visuo- Proprioceptive Illusion susceptibility in Individuals with High and Low Autism Traits

6.1 Introduction

Information about one's own hand position is critical for accurately reaching to targets, however, which sensory modality dominates and how the sensory information is combined to provide a single estimate of hand position remains largely unknown. Moreover, recently Sarlegna & Sainburg (2006) provided evidence suggesting that between vision and proprioception, vision is dominantly used to define trajectory and kinematics of any reaching movement, whereas, proprioception appears to be crucial in transforming this "visual plan" into motor commands sent to the arm muscles (Sarlegna & Sainburg, 2006; Apker et al., 2011).

It is well understood that the ability to successfully locate our body parts in space is fundamental for successful interaction with the environment and plays an extremely important role in the sense of bodily self. In order to understand and interact with the external world around the body, the brain must integrate information from multiple sensory modalities to construct a unified percept of the world around us. Furthermore, Makin et al., (2008) has suggested that integration of proprioception, vision and tactile inputs forms the basis of subjective sense of bodily self-awareness and body ownership, which is crucial for the development of imitation, self- awareness and empathizing (Schütz-Bosbach et al., 2006).

Unlike visuo- tactile integration in typical and atypical development, visual-proprioceptive integration is a relatively under researched area, especially in adults and children with atypical development compared to visual and auditory research. In a study conducted by Nardini et al., (2013) with 92 children aged between 4 to 12 years old and 17 adults, multisensory integration underlying hand localization was directly tested. The results of the study outlined that children aged seven to nine years of age and adults' hand localization estimates were more accurate when both proprioceptive and visual information was available regarding the limb, compared to only when either visual or proprioceptive information was present (Nardini et al., 2013). The outcome of their study suggested that optimal hand localization takes place when both visual and proprioceptive cues are available. On the other hand, Bremner et al., (2013) investigated visuo- proprioceptive integration using a mirror illusion task. In a group of five to seven years- old children and adults; participants left hand was reflected in a mirror placed between the hands so that it appeared on the right side of the body, however, it was not in the same actual location as the real hand (which was hidden from view). The task involved participants pointing with the unseen right hand to a visual target located to the right of the mirror. The results of the study outlined that children in all age groups and adults, the reaching movements came from the seen hand location, not the actual hidden right hand. This study provides support that visual inputs are normally a more reliable source of information regarding body localization and hand judgements, as opposed to proprioception (Bremner et al., 2013). Similarly, a study conducted by Touzalin-Chretien and colleagues

(2010) used brain EEG recordings during which contributions of vision and proprioception were measured for motor planning and hand movement. The results of the study indicated visual dominance over proprioception in a pointing task using the mirror illusion, similar to the one used in Bremner et al's., (2013) study (Touzalin-Chretien et al., 2010).

Nardini et al., (2008) investigated visuo- proprioceptive integration in two groups of children (aged between 4 to 5 years and 7- 8 years of age) and adults using an experimental task in which participants had to return an object to its original place in an artificial gaming arena. The results of the study outlined that both older children and adults' estimates were more accurate when both visual inputs and non-visual proprioceptive sensory inputs were available, as opposed to only visual or proprioceptive information was accessible. However, when visual and proprioceptive inputs were incongruent, adult's performance was based on a model of optimal integration such that their estimation and judgments relied on a weighted average of the two sensory inputs, while children alternated between using visual or proprioceptive information exclusively (Nardini et al., 2008). This is in line with past research which indicates that proprioceptive abilities are fully developed by the age of 16 years in individuals with a normal development, whereby, children before the age of 16 often tend to switch between visual and proprioceptive inputs depending on which input is more reliable and abundant (Ládavas and Pavani, 1998; Philip, 2010; Holst-Wolf et al., 2016).

With the help of the evidence provided above, it has been suggested that in healthy individuals combined visual and proprioceptive information facilitates the performance of hand localization tasks relative to a unimodal condition of only vision or proprioception (Touzalin-Chretien et al., 2010). Interactions between these two sensory inputs have been described in experiments introducing conflicts between the two senses (Hay et al., 1965; Michel et al., 2003; Berberovic & Mattingley, 2003) and in experimental studies with sensory deficit patients (Lajoie et al., 1992; Nico et al., 2004; Stenneken et al., 2006). Similar to sensory deficit patients, a growing amount of research now indicates that individuals with autism have atypical multisensory integration, especially in the area of visual and proprioceptive integration (Foss-Feig et al., 2010; Cascio et al., 2012) and that certain behavioral characteristics of autism are spread in the typically developing population and it is the number and severity of these that distinguish them from the clinical population (Happé et al., 2006b).

In terms of visuo- proprioceptive integration, there is not much research investigating MSI in individuals with high and low autism traits of typical development. However, limited research is available where visuo- proprioceptive performance has been tested in autism. Masterton & Biederman (1983) tested visual versus proprioceptive control in children with autism. They used a prism- induced lateral displacement task in order to test whether autistic children show a reliance for proximal rather than distant sensory sources. The researchers defined proximal sensory source as an internal input, i.e. proprioception, and distant as vision as it is an external source. The results gathered from their investigation outlined that autistic children displayed a reliance on proprioception rather than vision to complete the adaptation process. The researchers concluded that reliance on proprioception was used as an alternate strategy compensating for an inability to use vision (Masterton & Biederman, 1983). More recently, Hense et al., (2019) tested proprioceptive and visual influences on tactile processing in adults with autism spectrum disorders. These researchers argued that superior proprioceptive abilities and tactile dominance in autism might not be a genetic displacement but rather a developmental delay. In their study, adults with autism and matched- controls participants completed a tactile temporal order judgement task and visual cross- modal congruency task during which participants localized tactile stimuli to the fingers of each hand, while holding their fingers in a crossed or uncrossed position. Using Bayesian statistical modelling, the researchers found no group differences in performance between the two groups, however, performance of the autistic group got better with each trial compared to the control indicating that the autism group took a longer time to get used to the task. Researchers concluded that tasks that are designed to measure proprioception are relatively difficult to design as touch and proprioception are extremely interrelated. However, they did suggest that higher reliance on proprioception in autism could indicate a developmental delay rather than an over- reliance (Hense et al., 2019).

Palmer et al., (2013) investigated susceptibility to the rubber hand illusion in a group of typically developing adults with high and low autism traits measured using the Autism Spectrum Quotient (Baron-Cohen et al., 2001a). Following the induction procedure of the rubber hand illusion, during which synchronous brush strokes are applied to a seen, fake hand and the participants' unseen real hand, researchers found that hand localization estimates (termed as proprioceptive drift) were significantly closer to the fake rubber hand for the low AQ group compared to individuals with high autism traits. Even more, these estimates remained same for the low AQ group when the distance between the fake and real hands was increased by 10 cm. Paton et al., (2012) suggested that the low AQ group was influenced by the synchronous visuo- tactile inputs, therefore, estimating the hand to be closer to the fake hand. However, for the high AQ group hand localization estimates were more accurate (closer to the real hand) due to a bias for processing proprioceptive inputs over integrating visuo-tactile inputs (Nardini et al., 2013; Palmer et al., 2013).

In a more recent study, Palmer et al., (2013) investigated the susceptibility to the rubber hand illusion in a group of adults with ASD and a group of typical development individuals with high and low autism traits. However, this time around the results of the previous investigation (Palmer et al., 2013) were not replicated. Hand location estimations were closer to the fake hand, not the real hand, following synchronous brush strokes for all three groups. The only difference that was found in their study was the group differences in the extent of synchronous visuo- tactile inputs influenced hand movements. Unlike the low AQ group, the high AQ group showed a reduced effect of context indicating that hand movements were identical across both synchronous and asynchronous conditions. The authors suggested that, proprioceptive weighting in the high AQ group and the ASD group is less influenced by changes in the illusory context, hence, reducing the conflict between prior knowledge and incoming sensory inputs regarding the hand location (Palmer et al., 2013).

The results regarding hand localization (proprioceptive drift) obtained from the studies conducted by Palmer et al., (2013) and Ide & Wada (2016) make it difficult to interpret visuo-proprioceptive integration in those with high and low autism traits. These discrepancies in the findings could be due to behavioral differences or problems associated with the rubber hand illusion design itself in reference to the autistic perceptual style. Such as, the RHI requires a person to incorporate a fake rubber hand, overcome the visual discrepancies between the fake rubber hand and the real hand and also requires to pay attention to keep their hand still for several minutes. However, all these issues could be exaggerated for those with ASD or high autism traits mainly because of the attention deficits, a detail oriented perceptual style and imagination deficits seen in ASD (Leitner, 2014; Low et al., 2009). In order to avoid these issues, similar to the previous investigations, the MIRAGE system (Newport & Gilpin, 2011) was used. A MIRAGE hand localization task was used in the current investigation to evaluate whether individuals with high autism traits show an over reliance on proprioception compared to those with low autism traits. This task was similar to the one used in Bellan et al's (2015) study.

Bellan et al., (2015) investigated the amount of weightage visual and proprioceptive inputs have towards hand localization using a modified version of the original disappearing hand trick (DHT) (Newport & Gilpin, 2011). In their study, participants placed their hands inside the MIRAGE system and viewed their hands via the MIRAGE screen. Participants went through seen and unseen conditions, during which participants were asked to make judgements of their unseen finger. The conditions were as followed; participants went through three conditions (congruent seen, congruent unseen and in-congruent unseen). During the congruent seen condition participants were required to make judgement regarding the location of the finger when both vision and proprioceptive information was available. During the congruent unseen condition, the vision of the hand was obscured with a blank screen, however, the hand was proprioceptively aligned. In the third condition, incongruent condition, an adaptation procedure was used resulting in in- congruency between the location of the seen hand and the actual hand (different visual and proprioceptive information). During the adaptation period the spatial relationship between the seen location of the hand and its actual location was manipulated, during which the image of the right hand moved slowly towards the left at the rate of 4.5 mm/s. In order to keep the right hand in the same visual location, participants had to move their right hand for a period of 25 seconds after which the seen hand was viewed 11.25 cm to the right of its true location. The results of the investigation were such that, vision did play a role in localization estimates such that adults were more accurate in the congruent conditions compared to incongruent conditions. When there was an in-congruency between vision and proprioceptive information participants did rely more on vision than proprioception, as they made estimates closer to the last seen location of the hand. However, when the vision was absent, this shift happened more quickly (Bellan et al., 2015).

The current experiment investigated whether individuals from the general population with high and low number of autism traits show an over- reliance on proprioception (as suggested in previous investigations, such as Palmer et al., 2013; Paton et al., 2012; Greenfield et al., 2015) using a hand localization task, similar to the one used in Bellan et al's (2015) study, in order to investigate visual and proprioceptive integration. For the current study, it is predicted that participants in both high AQ and low AQ groups will be more accurate at localizing their hand when presented with congruent compared to incongruent visuo-proprioceptive information. Previous studies have suggested an over-reliance on proprioception in individuals with high autism traits and those with ASD (e.g. Palmer et al., 2013; Marko et al., 2015), therefore, it is predicted that high AQ scorers will be consistently more accurate in hand localization, regardless of congruent or incongruent conditions, instead of integrating and being influenced by the visual input. Furthermore, I predict that participants with low autism traits would be more accurate in congruent condition (when vision and proprioception are synchronous) compared to incongruent condition.

6.2. Method

6.2.1. Design

A mixed design was used with group being the between subjects-factor (high AQ vs Low AQ groups) and condition being the within-subject factor (Congruent seen Vs Congruent Unseen Vs Incongruent Unseen Conditions (when the hand was displaced 150 units), the dependent variables being estimation scores during all the conditions presented to the participants.

6.2.2 Participants

Participants were forty- four (44) right- handed adults aged 18 to 50 years old (mean age = 22.68, SD = 3.01). All participants were recruited via posters placed around the University Park campus at the University of Nottingham. None of the participants who took part in the current investigation. All respondents reported normal or corrected to normal vision, and no sensory deficits *(see table 6.1 for participant demographics).* Written and informed consent was obtained from all participants before prior to testing. Ethical approval was granted by the University of Nottingham, School of Psychology Ethics Committee and was conducted in accordance with the ethical standards of the Declaration of Helsinki.

	No. of Participants	**Mean age *(std)***	**Average AQ Score *(std)***
High AQ	22	22.72 *(3.04)*	36.50 *(4.59)*
Low AQ	22	22.63 *(3.03)*	18.36 (5.27)

Table 6.1 Participant demographics based on AQ scores and High AQ and Low AQ groups. Participants were selected to take part in the investigation based on their AQ scores. A score of 32+ was used as a cut off for the High AQ group. Participants were not informed about their group allocations.

6.3. Experimental Conditions and Procedure

The hand localization task used in the current investigation was similar to the one used in Bellan et al's., (2015) study, which is based on the original disappearing hand trick (DHT) using the MIRAGE apparatus (Newport & Gilpin, 2011). The MIRAGE system was used in the current investigation to measure visuo- proprioceptive integration in a hand localization task in individuals with high and low autism traits.

Unlike the previous studies, the current investigation did not consist of any subjective measures, aside from the acclimatization questionnaire which was not used as a part of the main analysis. The original disappearing hand illusion (Bellan et al., 2005; Newport & Gilpin, 2011) consists of two parts, part one where participants go through the adaptation process while looking at their hand through the screen and part two where the experimenter asks the participant to rate their experience of the illusion after they have estimated the location of their hidden hand which has moved from its original location. The statements used during the original DHT illusion were directed towards understanding whether participants thought their hand had "disappeared" or whether the hand is "no longer a part of their body"; mainly questions associated with the participants reaching for their hand after it has been displaced to a certain distance. Therefore, the current study eliminated the subjective measures as we were more interested in understanding how the two groups would perform in locating their fingertip in different conditions when visual and/ or proprioceptive information is provided.

The experimental task required the participants to make location judgements of their seen and unseen right index finger by verbally stating when a red arrow moving laterally was aligned with their index finger (Figure 6.1) in three different conditions: *(i)* congruent seen, *(ii)* congruent unseen and an *(iii)* incongruent unseen conditions. Participants sat and placed their hands on the work surface of the MIRAGE apparatus, as if viewing their hands in same spatial and visual location. A black bib was attached around the participant's shoulders to obscure a direct view of their upper arm. Written consent was obtained prior to testing.

Figure 6.1 *Finger Localization judgements. Respondents were required to make estimation regarding the location of their seen or unseen finger in all the conditions by indicating when the right arrow moving laterally across the MIRAGE screen was aligned with the location of their right index finger. The image above shows the localization task during the congruent seen condition. During all other conditions the view of the hands was obscured.*

(i) Congruent Seen condition:

This condition was used a control condition with the primary purpose of ensuring that the participants understood the experimental task and to measure that participants could accurately locate the right index finger when both visual and proprioceptive information was congruent. After the participant had placed his or her hands with in the MIRAGE apparatus, they viewed the experimenter move their hands to a pre- specified location. Participants were asked to view their hands through the MIRAGE screen and were instructed to keep their hands still. Soon after, participants saw a red arrow (on top of the MIRAGE screen) moving laterally across the MIRAGE screen and they were instructed to say 'stop' when they thought that the arrow was perfectly aligned with the index finger of their right hand. For each participant, they made estimation twice, once when the arrow moved from the right side of the screen to the left and then when the arrow moved from the left of the screen to the right-hand side. The order of presentation of the direction of the arrow was counterbalanced between all participants and conditions.

(ii) Congruent Unseen Condition:

Participants' hands remained in the same location as in the previous condition, congruent seen condition, but the vision of the hands was obscured and was replaced with a blank screen.

After which participants were required to make the finger localization judgements again, once when the arrow moved from the right to left and then when the arrow moved from left to right indicating when they thought the arrow was aligned with the finger. The primary aim was to assess how accurate the participants are when only proprioceptive information is available, without visual input.

(iii) Incongruent Unseen Condition (Experimental condition):

The participant placed his or her hands inside the MIRAGE apparatus and kept them hovering in the air approximately 5 cm above the MIRAGE surface and were instructed to keep them steady and were asked to make sure to not touch the blue bars that were present on their side of the hands and one in the middle on the MIRAGE screen (See Figure 6.1). The blue bars were superimposed on the MIRAGE screen and expanded slowly over the time course of 25 seconds that resulted in the constriction of the space in which the hands are present. An adaptation procedure was used during this time, during which time the seen location of the hand and its real location was manipulated. This procedure was similar to the one used in Bellan et al's (2015) study. During the expansion of the blue bars, the image of the right hand moved slowly towards the left at the rate of 4.5 mm/s. Thus, unknowingly, participants had to move their hand towards the right at the same time, which after 25 second resulted in the seen hand being, viewed 11.25 cm towards the left of its actual location. During this time, the left hand oscillated towards the left, but over the 25 seconds the hand ended up in the same location as it had started. After this adaptation procedure, the experimenter slowly placed the hands of the participants on the MIRAGE surface and the vision of the hands was obscured. After which the finger localization judgements were recorded twice, once arrow moving from right to left and then from left to right. For the incongruent unseen condition, participants made finger localization judgements three, with thirty second interval between each set of finger judgment. However, the adaptation procedure was only completed once, followed by three sets of finger localization judgment with two estimations in each set.

6.3. Results

6.3.1 Data Analysis

For the hand localization estimates, the data collected from the trials was in pixels. For each estimate the distance between the location of actual fingertip and where the participant made the estimate was recorded in pixels which were later converted into cm. The area of the work surface of the MIRAGE was premeasured using a grid (length and width) and the dimensions of the screen through which the participants saw their hands were inputted into online software to obtain the dimensions in cm. Once the participants' estimation scores were obtained, the screen dimensions, along with the pixels (units) were converted using online software to achieve an average estimation score in cm. During each trial, participants made two judgements (first from left to right and then from right to left of the screen), the scores for the two were averaged and used as a "mean estimation score". A score of zero would state accurate estimation of hand position. A negative score would represent estimations towards the left-hand side and a positive score would represent estimation towards the right of the hand.

Participants in each group were given a brief acclimatization period during which participants were allowed to view their hands through the MIRAGE screen and get used to the experimental set-up. As a means to measure the ownership given to the hands through the

MIRAGE screen, three acclimatization questions were asked verbally and the respondents rated them on a 7.0 rating scale (-3 = Strongly Disagree, 0 = Neutral, 3 = Strongly agree). The scores for the three statements were averaged to achieve a single acclimatization score for each participant; t- tests were used to calculate the differences between groups. For the analysis of the estimation scores, a 3 (conditions) x 2 (groups) Mixed ANOVA was used. Pairwise comparisons (Bonferroni- corrected) were used to assess any main effects and independent samples t- tests (Bonferroni corrected) were computed to test any significant interactions.

6.3.2 Acclimatization Scores

The ratings for statements (i) The hands that I see are my own hands, (ii) The hands that I see in the screen belong to me, and (iii) the hands that I see in the screen are a part of my body were averaged to achieve a single "ownership score" for each participant. An independent samples t- test was conducted to compare the averages of the high AQ and low AQ groups and did not reveal a significant difference in acclimatization scores, $t\ (2, 24) = .245, p = .807\ (\eta^2 = .011)$. This suggests that the high AQ group *(Mean = 2.89, SD = .189)* and low AQ group *(Mean = 2.87, SD = .22)* gave similar amounts of ownership over the hands viewed through the MIRAGE screen (Fig 6.2).

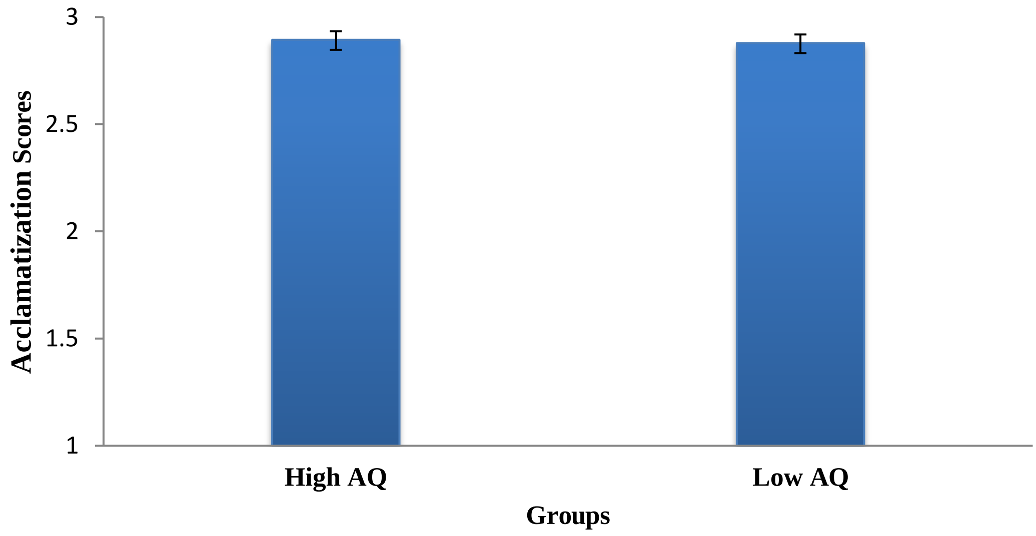


Fig 6.2 Graphical representation of the acclimatization scores given by the respondents in the high AQ and Low AQ groups. Both groups gave high amounts of ownership over the digitally presented hands as viewed by the high positive ratings with no statistically significant difference between groups.

6.3.3 Hand Localization Estimates

A 2 (Groups: High AQ vs Low AQ) x (Three conditions: Congruent seen vs Congruent Unseen Vs Incongruent Unseen) Repeated Measures ANOVA was conducted to test for any main effects and interactions. A 2 x 3 Repeated Measures ANOVA revealed a main effect of condition, $F\ (2, 42) = 1319.82, p < .001$ ($\eta^2 = .969$) indicating differences in hand localization across conditions. Pairwise comparisons (Bonferroni- corrected) revealed a significant difference in localization estimates between congruent seen and congruent unseen conditions, $p < .001$, ($\eta^2 = .622$), indicating that estimation scores were closer to the actual location during the congruent seen *(Mean = .075, SD = .003)* compared to congruent unseen *(Mean = .277, SD = .012)* conditions. A significant difference was also found between congruent seen and incongruent unseen conditions, $p < .001$, ($\eta^2 = .443$), suggesting that estimation scores were more accurate in the congruent condition *(Mean = .075, SD = .003)* compared to the incongruent unseen condition (*Mean = - 3.698, SD = .106)*. A significant difference was also found between incongruent unseen and congruent unseen conditions, $p < .001$, ($\eta^2 = .411$), indicating that there were more displacement errors in hand localization during the incongruent condition *(Mean = -3.69, SD = .106)* compared to congruent unseen condition *(Mean = .277, SD = .012)*.

There was also a significant interaction between groups (High AQ vs Low AQ) and Conditions (congruent seen, congruent unseen and incongruent unseen), $F (2, 42) = 111.12$, $p < .001$ ($\eta^2 = 7.26$). Independent samples post hoc t- tests (Bonferroni-corrected) revealed no significant differences in hand localization scores between high AQ and low AQ groups in the congruent seen condition, $p = .311$, ($\eta^2 = .514$). The High AQ group average hand localization score during the congruent seen condition was *.077 (SD = .02)* and for the low AQ group the average score was *.072 (SD = .03)* indicating no significant differences between the groups. As the values are closer to "0" this suggests more accuracy in estimating the location of the right index finger and lesser displacement errors. Similarly, there was no significant differences in hand localization scores in the congruent unseen condition between groups, $p = .052$, ($\eta^2 = 1.23$). The average estimation score for the high AQ group in the congruent unseen condition was *.254 (SD = .072)* and for the low AQ group was *.301 (SD = .082)*. As the scores were closer to mid-point ("0") the averages of both the groups suggest closer estimation to the location of the actual fingertip during the unseen condition, indicating lesser displacement errors. However, there was a significant difference in average estimation scores between groups during the incongruent unseen condition, $t (2, 42) = 10.51$, $p < .001$, ($\eta^2 = .491$), indicating that respondents in the low AQ group *(Mean = - 4.81, SD = .769)* made estimates further away from the mid- point (original hidden location of the finger) compared to the high AQ group *(Mean* = - *2.58, SD* = *.631)*. However, both groups displacement errors were in the negative range indicating that estimations were made based on the visual input or where they last saw their finger.

Figure 6.3 below displays the average estimation scores for both the groups across all conditions. As stated before, all negative values indicate estimates towards the left of the hand, whereas, positive estimates indicate estimation towards the right of the hand and ‘0’ indicates the midpoint. Both groups had minimal displacement errors during the congruent seen and unseen condition, however, displacement errors increased during the incongruent unseen condition. This is due to the visual and proprioceptive information being mismatched during this condition (see section 6.4 for further details).

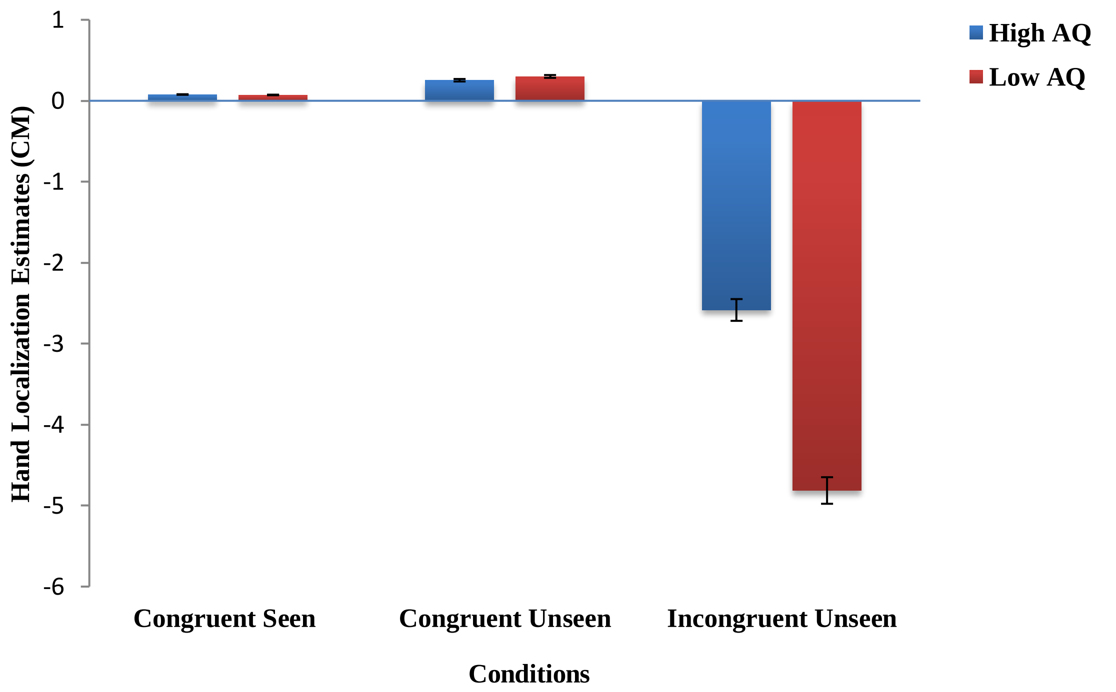


Fig 6.3 Average hand localization task errors in cm for the High AQ (blue bars) and Low AQ (red bars) groups across all three conditions. Positive values in the bar chart represent hand estimation to the right side of the actual hand and negative values indicate estimates towards the left of the actual hand. Hand localization estimation errors are low in both congruent conditions (Congruent seen and congruent unseen condition), therefore, no significant differences were found between groups during the conditions. However, there is an increase in the displacement errors when visual and proprioceptive information is mismatched in the incongruent condition indicating that estimation scores were significantly different between groups during the incongruent

6.4 Discussion

The current study investigated the differences in susceptibility between individuals of typical development with high and low autism traits towards a visuo- proprioceptive illusion presented through the MIRAGE system. During this illusion participants were presented with three different conditions (congruent seen, congruent unseen and incongruent unseen condition) during which they were required to take part in a hand localization task[13] that measured how accurate participants were in estimating the position of their hand when it was displaced from its original location. It was predicted that participants, regardless of the groups, would be better at hand localization during congruent conditions instead of incongruent conditions. This was the case as suggested by the data gathered; participants in both groups made the least amount of displacement errors in hand localization during the congruent seen and unseen conditions indicating that they were more accurate in locating their hand when both visual and proprioceptive information were available. This finding is in line with the investigation carried out by Bellan and Colleagues (2015) investigating visuo- proprioceptive integration in hand localization using a similar procedure (Bellan et al., 2015). It is important to note that neither groups were absolutely accurate and this can be associated with the difficulty of the task.

[13] During this task, participants were required to estimate the location of the right hand, however, the right index finger was used as a reference for the participants.

Furthermore, the accuracy in hand localization task also remained accurate when the visual input was removed and participants were required to make judgments regarding the location of the hand. Compared to the congruent seen condition, participants did make slightly more displacement errors in the congruent unseen condition; however, as indicated by the results, these displacement errors were minimal and can be associated with estimation based on prediction when vision is not available. During the congruent unseen condition, participants were required to make judgements regarding the location of the right index finger without any visual input. However, in the previous condition participants viewed their hands in a certain location before the visual input was blocked. Therefore, accuracy in this condition can be associated to the fact that the visual capture from the previous condition was over- ridding the proprioceptive information (Guerraz et al., 2012). It is also to be noted here that, even though the visual input regarding the hand was blocked in this condition, proprioceptive information regarding the hand was not manipulated. Hence, helping in more accurate estimation regarding the hand location if one was indeed relying on this sense more. Furthermore, it has been stated that visual input is given more weightage compared to other sensory inputs (Tsakiris & Haggard, 2005; Stenneken et al., 2006; Tsakiris, 2010; Tsakiris, 2011), therefore, during this condition participants judgments could be based mainly on the visual input gathered during the previous condition (congruent seen condition), therefore, using this knowledge to base their judgements. This is a finding reported by Bellan et al (2015) as well.

During the incongruent unseen condition, participants in high and low AQ groups made the highest number of displacement errors in estimating the location of their hand. This highlights that accuracy was significantly reduced when visual and proprioceptive information regarding the finger location were incongruent, replicating Bellan et al's., (2015) finding. Participants in the current study were required to estimate the location of the hidden finger three times (six judgements in total) following a 25 seconds adaptation procedure once. When the data across the trials was averaged it showed (Figure 6.3) that both groups' averages were more towards the left-hand side of the actual hand (where they saw the hand in the previous conditions) as opposed to the location of the real hand, indicating that their estimation was based on the location of the hand where it was viewed previously. One possible explanation for this could be that the visual capture during the previous conditions dominates the proprioceptive information (Guerraz et al., 2012) indicating a higher reliance on visual input. Various behavioral experiments using different techniques (such as prisms or mirrors) have suggested that visuo- proprioceptive information regarding limb position is integrated based on the reliability of the unisensory modalities, with vision usually "dominating" proprioception due to its higher spatial acuity (Holmes & Spence, 2005; Van Beers et al., 1999), which is also reported during the rubber hand (Botvinick & Cohen, 1998) in which the visual position from rubber hand "overrides" proprioceptive information after co-stimulation of the rubber hand and the real hand.

Alternatively, it could be suggested that atypical multisensory integration could be specific to clinical autism, such that it is only seen to a certain extent in those with individuals with high and low autism traits. However, findings from the previous studies that I have conducted could argue with this idea. Furthermore, the data collected during the incongruent condition in the current study indicates a difference in hand displacement errors between the high AQ group and low AQ group. Therefore, it can be suggested that the limited number of trails in the current study could not reveal a difference in performance between groups in the incongruent condition. This has been studied in (Bellan et al., 2015) study during which initially participants estimated the location of the hand closer to the last seen location, however, over trails their estimates shifted towards the actual location of the hand. Furthermore, Bellan et al's., (2015) study was conducted on adults and children of typical development, therefore, only limited predictions can be made regarding its effects on the autistic population. Recent research investigating multisensory integration in autism has suggested that individuals with autism do tend to integrate sensory information from multiple sources, however, differences in performances are only apparent when the participants are taken through the task multiple times (Foss-Feig et al., 2010; Greenfield et al., 2015). Thus, in conclusion, the following chapter would be addressing these methodological issues in the current experiment, firstly by introducing more trails in each condition, especially the incongruent unseen condition to measure the differences in performance after a specific number of trails and each trail presents the participants with more displacements to test whether increasing the distance between the location of the actual hand and the seen hand can have an impact on judgement. Secondly, in order to test if atypical visuo- proprioceptive integration is present in autism, I will be conducting the following study with adults with high- functioning autism and typically developing matched controls.

Chapter Seven

Experiment Six

Visuo- Proprioceptive illusion susceptibility in Individuals with High-Functioning Autism and Typically Developing Adults

7.1 Introduction

Visuo-proprioceptive integration is studied widely in the typically developing population using different types of hand localization tasks (Bremner et al., 2013; Bellan et al., 2015; Greenfield et al., 2015). The results of these studies have suggested that participants are more accurate in locating the position of their limb when both proprioceptive and visual information are available, however, estimates regarding limb position are less accurate when only one sensory input is available, for example only visual input or proprioceptive information (Nardini et al., 2013). Furthermore, studies have also demonstrated that visual inputs are generally more reliable and opted for in tasks requiring limb localization (Bremner et al., 2013). Research has demonstrated that children and adults optimally integrate both proprioceptive knowledge and visual inputs in order to make estimates regarding the location of the hand, rather than relying on a unimodal sensory source (Touzalin-Chretien et al., 2010).

Recent emerging evidence indicates that individuals with autism tend to rely more on singular sensory input (i.e. proprioception) rather than integrating both multiple sensory inputs (i.e. vision and proprioception) which is the hallmark of healthy sensory integration (Schauder et al., 2015a; Moore et al., 2009; Park et al., 2017) . Research investigating sensory susceptibility in autism often looks at the external sensory sources, i.e. visual input, auditory input or tactile inputs, whereas, an important element of multisensory integration is proprioception which co-exists with tactile inputs. Hence, in order for successful visuo- tactile integration to take place, one needs to integrate visual and tactile inputs in an optimal manner, where proprioception plays a key role (Petersen et al., 2003; Dinstein et al., 2012; Haigh et al., 2015). It is a well- known fact that individuals with autism tend to display hypo- or – hyper responsiveness to sensory stimuli, whereby, tactile sensitivity is reported in almost all individuals with autism (Güçlü et al., 2007; Brett-Green et al., 2008) . Therefore, it has been suggested by researches that this could be due to an over- reliance on internal sensory cues (i.e.

proprioception) while ignoring external sensory inputs (i.e. vision or touch) (Masterton & Biederman, 1983; Park et al., 2017; Vilidaite & Baker, 2017; Hense et al., 2019). Therefore, keeping this in mind, research that indicates that individuals with autism tend to show an over-reliance on proprioception (Foss-Feig et al., 2012; Paton et al., 2012; Palmer et al., 2013; Cascio et al., 2015) could be because this population is more in- tune towards their internal sensory cues or sensory information arising from within i.e. proprioception, rather than integrating visual and tactile inputs successfully. Hence, if individuals with autism do rely more on internal sensory cues they would show superior performance in tasks such as limb localization or estimation tasks.

Therefore, hand localization task was used with three different conditions, congruent seen, congruent unseen and an incongruent unseen condition. The first condition was used to measure how accurate participant's finger estimates are when both visual and proprioceptive information is available. During the second condition, participants were tested on how accurate their estimation scores are when only proprioceptive information is available; however, the visual location of the hand is congruent to the actual hand, therefore, judgements should reflect performance based on cognitive knowledge regarding the limb i.e. where was the hand last seen. In the incongruent unseen condition, visual and proprioceptive information was manipulated in such that following an adaptation procedure the right hand was displaced towards the right[14] in three different displacements (distances from the midpoint) after which participants were required to make estimates of the right index finger without any visual input. Three different displacements were added to the incongruent unseen condition for mainly two reasons, firstly, according to Bellan et al's (2015) study, it was shown that when both vision and proprioceptive location of the limb were manipulated participants initially made

[14] The adaptation procedure was similar to the one used in the previous investigation which was adapted from (Newport & Gilpin, 2011).

judgements based on their visual input, i.e. demonstrating higher displacement errors, however, over trails they switched to using both inputs to make judgment's which resulted in lesser displacement errors. However, Bellan et al's (2015) study was conducted on typically developing children and adults, therefore, to investigate whether similar protocols exist for the HfA population more trails were added. Secondly, adding more trails increased the exposure of the participants towards the illusion and this meant that with each increase in distance participants had more attempts to acclimatize to the illusory environment. This was based on the idea that individuals with autism require more time to adapt to the illusory paradigm (Foss-Feig et al., 2010; Greenfield et al., 2015; Powers et al., 2016) which suggests that participants with autism are equally susceptible to multisensory illusions, however, they may require more attempts at the illusionary percept compared to TD population. Being exposed to the illusion for a longer period is a rather recent theory, therefore, in order to test this, three different displacements were added to the task to test whether with more exposure they could show embodiment of the illusion, i.e. the HfA group switch their estimates from the proprioceptive field towards the visual field.

Findings from the previous investigation (Chapter 6) indicate that overall individuals with high autism traits were more inclined to make estimations in the visual field rather than the proprioceptive field as both groups' mean displacement errors were negative. In order to further explore this, three different distances were added to understand whether over several trails' estimations could change for both groups or if over different distances one or both groups get better at the estimation tasks and to see if the effect of the illusion is reduced after a specific distance. Also, according to Bellan et al's., (2015) investigation it was reported that participants were better at estimating the location of their hands over several trails indicating that with each trail participants displacements errors reduced. Lastly, a study conducted by Goris and colleagues (2019) used a 3-dimensional task during which the performance of participants with high and low autism traits and those with an autism disorder was compared in which both groups were required to locate objects in a virtual environment using their hands in different conditions. The results of the investigation suggested that the autistic group did significantly better in location objects, whereas, the high AQ group scored lower than the autistic group. Keeping in line with this idea, the previous investigation indicated that both high and low AQ groups estimated the location of their hand where they last saw it, however, the high AQ group did have significantly lesser displacement errors compared to the low AQ group (Goris et al., 2019). Therefore, it could be suggested that individuals with a formal diagnosis of autism could be more inclined with their internal sensory sources, hence, performing better at tasks requiring proprioceptive information.

Therefore, it is predicted that both groups will be highly accurate in the localization task when both visual and proprioceptive information are available and congruent, therefore, making lesser displacement errors. Furthermore, keeping in line with Palmer et al., (2013) and Marko et al's., (2015) studies that suggest an "over- reliance on proprioception during hand localization in the autistic population", I predict that the HfA group will have fewer errors in estimating the location of the right index finger when no visual input is provided and also when both visual and proprioceptive information is manipulated. Therefore, an over- reliance on proprioception would indicate better localization regardless of the condition for the HfA group as they would be less influenced by the visual input. More so, if there is an over- reliance, we could expect judgements more in the proprioceptive field (Figure 7.1 below explains this using a visual diagram). Furthermore, it is also predicted that during the incongruent unseen condition, participants from both groups would get better at estimating the location of their hand over trails, hence, leading to lesser displacement errors. This is based on the findings of Bellan et als., (2015) investigation.

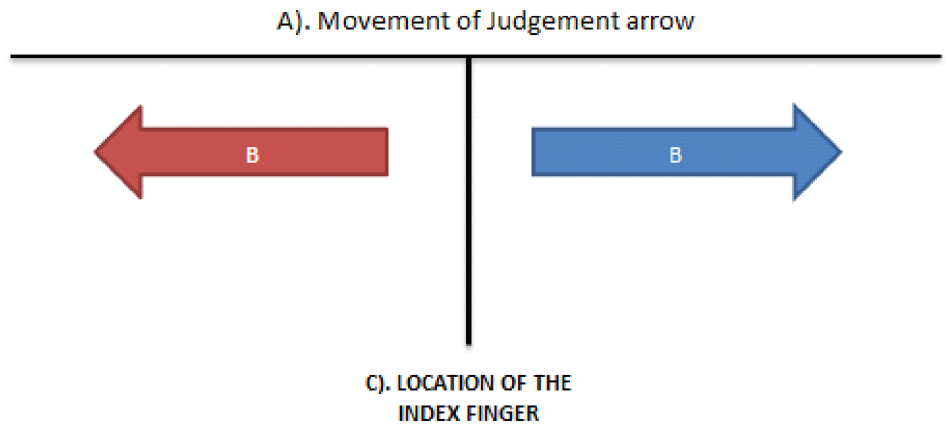


Figure 7.1 This diagram is provided to aid the understanding of the reader. A = refers to top of the screen where the participant would view the arrow for the judgment. B (red) = represents the visual field and B (blue) = represents the proprioception plains. The midline represents the location of the index finger after the adaptation procedure is over. Therefore, in the context of the current investigation, we would expect HfA adults to make judgments on the proprioceptive field (Blue Arrow).

7.2 Method

7.2.1 Design

A mixed design was used with group being the between subjects-factor (HfA vs TD participants) and condition being the within-subject factor (Congruent seen Vs Congruent Unseen Vs Incongruent Unseen Conditions (when the hand was displaced 100 units, 120 units and 150 units), The dependent variables being estimation scores during all the conditions presented to the participants. The acclimatization scores were not used during the data analysis, as the acclimatization period was used prior to the experimental task.

7.2.2 Participants

Given the large variation in cognitive impairments seen in autism spectrum disorders, only individuals with a clinical diagnosis of high- functioning autism were recruited. This consisted of fifteen right handed adults (8 males and 7 females) with high functioning autism (HfA) aged between eighteen to twenty-eight years of age (Mean age = 22.2 years, SD = 2.62). A comparison group of fifteen (9 females and 6 males) age matched typically developing adults (Mean age = 22.0 years, SD = 2.91) were also recruited. These were the same participants that took part in the previous experiments (Chapter 3 & 5).

The status of the clinical group as "high- functioning" was reconfirmed by their performance on a standardized cognitive assessment, Wechsler Adult Intelligence Scale – fourth edition (WAIS-IV). Groups were matched on the overall Intelligence scores, where there was no significant difference found between the full-scale IQ of the HfA and comparison group, $t(2, 28) = -.168$, $p = .868$. (Please see page 85, Chapter 3, Section 3.2 for a detailed description of the participants)

7.2.3 Experimental Conditions

(i) Congruent Seen Condition (CSC):

This condition was used a control condition with the main objective of testing how accurate participants were in estimating the location of the right index finger when both visual and proprioceptive inputs were available. The participants were required to place their hands within the MIRAGE system and the experimenter moved their hands to a pre- specified location. Soon after, a red arrow (on top of the MIRAGE screen) moved laterally across the MIRAGE screen and they were instructed to verbally say 'stop' when they thought the arrow was aligned with the right index finger. For each participant, in this condition, estimations were made twice, once from the right side of the screen to the middle and then from the middle of the screen moving to the right side. This counted as a single set and participants completed two sets of estimation in this condition. This condition also served as a means to make sure that the participants understood the experimental task.

(ii) Congruent Unseen Condition (CUC):

This condition was an extension of the previous condition (congruent seen), where the participants' hands remained in the same location as they were before, but the vision of the hands was obscured and was replaced by a blank screen. This condition served as a control condition also, along with testing how accurate participants would be in estimating the location of the hidden finger without any visual input, making judgments based on proprioceptive input. Similar to the previous condition, after the visual input was blocked, participants made finger location estimates by directing the red arrow for a total of two sets of estimates.

The order of presentation of the direction of the arrow was counterbalanced between all participants and conditions.

(iii) Incongruent Unseen Conditions (IUC)

This condition served as the main experimental condition during which the visual and proprioceptive information regarding the participant's right hand were manipulated to test accuracy of hand localization. Unlike the previous study, each participant went through the adaptation procedure three times and for each of the adaptation period the location where the hand would move to after the adaptation procedure was manipulated. Three manipulations were applied, during which the right hand would be displaced either *(i)* 100 units (7.5 cm) to the right of the original location, *(ii)* 120 units to the right, or *(iii)* 150 units to the right of the original location of the hand. Participants were given a two-minute break between each adaptation procedure after which they were required to make estimates regarding the right index finger.

The adaptation procedure lasted for a total of 25 seconds and to make sure that the movement was balanced, the left hand also moved towards the left side of the screen, however the movement resulted in the hand image returned back to its original position. After the adaptation procedure ended, the experimenter slowly placed the hands of the participants on the MIRAGE surface and the vision of the hands was obscured. After this, the hand localization task began. For each participant, each set consisted of two estimations (once arrow moving from right to the middle of the screen and then from the middle to the right side of the screen). Each participant made 4 sets of estimations in each of the displacements (100 units, 120 units and 150 units) with a one-minute interval between each set of finger judgment. This was done to see if the performance between the perceived location of the finger and where it actually is increases or decreases over trails.

7.2.3. Procedure

The hand localization task used in the current study is identical to the one used in Chapter 6 and is based on the task used in Bellan et al's., (2015) study. The MIRAGE apparatus (Newport & Gilpin, 2011) was used in the current investigation to measure visuo-proprioceptive susceptibility using a hand localization task in adults with high- functioning autism and an age and IQ matched control group. Participants were required to make location judgments of their seen and unseen right hands index finger by verbally stating when a red arrow moving laterally was aligned with their right index finger in three different conditions, where the third condition was presented in three different variations.

Participants sat and placed their hands on the work surface of the MIRAGE apparatus, viewing their hands through a live video footage displayed on the screen above the work surface, enabling participants to viewing their hands in the same spatial and visual location as the real hands. A black bib was attached around the participant's shoulders to obscure a direct view of their upper arm. All participants gave written consent before obtaining prior testing. Before taking part in the experimental task, participants were required to fill out the Autism Spectrum Quotient (Baron-Cohen et al., 2001a) presented in either paper format or on a computer.

All participants began by placing their hands inside the MIRAGE apparatus and were asked to keep them hovering in the air approximately 5 cm above the surface of the MIRAGE. Preset, superimposed bars were already set on the MIRAGE screen before the participants began and they were required to keep their hands within the blue bars that were presented on either side of the hands and one in the middle (see figure 7.1). Participants were instructed to keep their hands within the blue bars. After which the adaptation procedure began. During the adaptation procedure, the blue bars expanded slowly towards the hands over a time course of 25 seconds that resulted in restricted space of the hands were present in. During the narrowing of the blue bars, the image of the hand moved slowly towards the left at the rate of 4.5 mm/s. Participants were explicitly instructed to verbally instruct the experimenter to stop the movement of the arrow which moved vertically across the screen. As an added measure, the right index finger was used as a reference, therefore, participants were to say stop when the arrow was aligned where they though the right index finger was.

Figure 7.2 Finger Localization judgements. Respondents were required to make estimation regarding the location of their seen or unseen finger in all the conditions by indicating when the right arrow moving laterally across the MIRAGE screen was aligned with the location of their right index finger. The image above shows the localization task during the congruent seen condition. During all other conditions the view of the hands was obscured.

7.3 Results

7.3.1 Data Analysis

For the finger estimations, the data collected from the trials was in pixels. For each estimate, the distance between the location of the actual index finger and where the participant stopped the red arrow was recorded in pixels which was later converted into cm. The area of the work surface of the MIRAGE was pre- measured using a grid (length and width) and the dimensions of the screen through which the participants saw their hands were inputted into an online software to obtain the dimensions in cm. Once the participants estimation scores were obtained, the screen dimensions, along with the pixels (units) were converted using online software to achieve an average estimation score in cm. During the congruent conditions, participants made two sets of judgements (each set contained two estimates from opposite directions) which were averaged and used as a mean estimation score. For the incongruent conditions, three different hand displacements were used during the adaptation procedure; during each of the displacement's participants made 4 sets of judgments (4 estimates from the right of the screen to the middle and four from the middle to the right of the screen). In the analysis, a score of zero indicated accurate estimation; a negative score indicated estimation towards the left of the hand and a positive score would indicate estimate towards the right side of the hand. A Mixed ANOVA was used to analyze the differences in the estimation scores. Bonferroni Pairwise comparisons (Bonferroni- corrected) were used to assess any main effects and independent samples t- tests (Bonferroni- corrected) were computed to test any significant interactions.

Similar to the previous study (Chapter 6) participants were given a brief acclimatization period during which participants were allowed to view their hands through the MIRAGE screen and get used to the experimental apparatus. During this period, they were asked to rate three acclimatization statements on a 7.0 rating scale (-3 = strongly Disagree, 0 = Neutral, 3 = Strongly Agree). The scores for the three statements were averaged to achieve a single acclimatization score for each participant. The acclimatization scores were not used as a part of the finger estimation analysis; however, they were only used to measure the amount of ownership given over the hands as displayed through the MIRAGE system.

7.3.2 Acclimatization Scores

Ratings for statements (i) *The hands that I see are my own hands*, (ii) *The hands that I see in the screen belong to me*, and (iii) *the hands that I see in the screen are a part of my body* were averaged to achieve a single "ownership" score for each participant. An independent samples t- test was run to compare the averages of the HfA and control groups and did not reveal significant differences in acclimatization scores, $t\ (2, 28) = -1.095$, $p = .283$ ($\eta^2 = .001$). This indicates that the HfA group *(Mean = 2.71, SD = .33)* and control group *(Mean = 2.82, SD = .21)* gave similar amounts of ownership over the hands viewed through the MIRAGE screen (Fig 7.3).

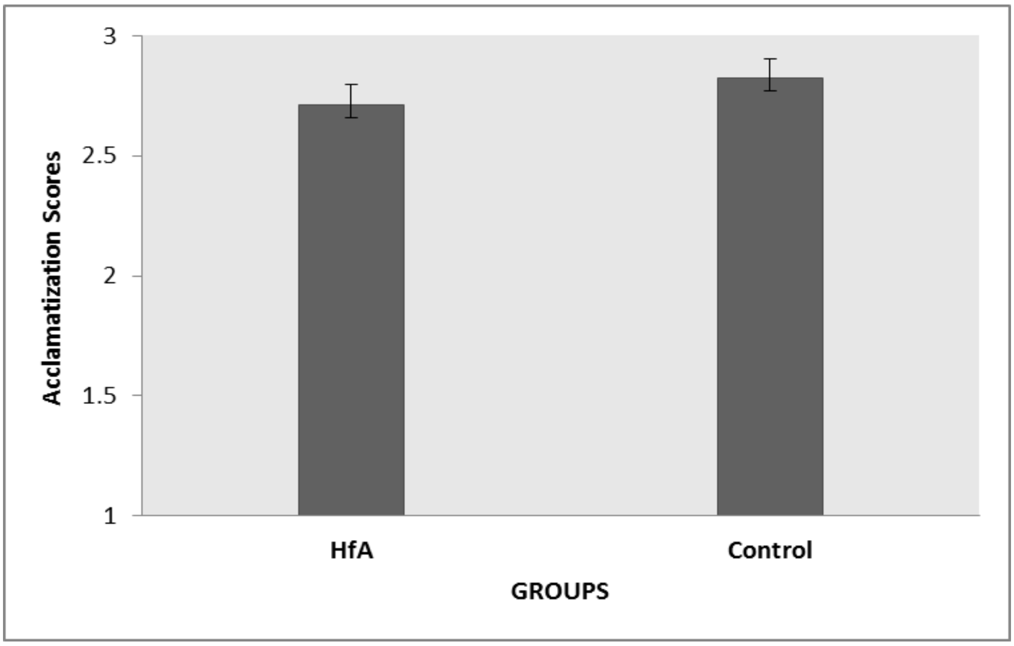


Fig 7.3 Graphical representation of the acclimatization scores given by the respondents in the HfA and Control groups. Both groups gave high amounts of ownership over the digitally presented hands as viewed by the high positive ratings with no statistically significant difference between groups

7.3.3 Hand localization Estimates

In order to examine the differences between groups (HfA Vs Controls) during the hand localization task during the three displacements (100 units, 120 units and 150 units) A 2 (Groups: HfA vs Control) x 3 (Hand Displacement: 100 units x 120 units x 150 units) Repeated Measures ANOVA was run to test for any main effects and interactions between the estimation scores given by the participants during different hand displacements. There was a significant main effect of condition, $F(2, 28) = 132.43, p < .001$ ($\eta^2 = .825$), indicating differences across conditions. Pairwise comparisons (Bonferroni corrected) revealed a significant difference in finger estimation between when hand was displaced 100 units and 120 units from its original location, $p < .001$, ($\eta^2 = .323$), indicating that estimates were closer to the original location of the finger when the hand was displaced 100 units *(Mean = - .198, SD = .096)* from its original location compared to a 120 displacement *(Mean = - 1.752, SD = .191)*. A significant difference was also found between 120 units of displacement and 150 units of displacement, $p < .001$, ($\eta^2 = .737$), indicating that estimation errors were less during the 120 units of displacement *(Mean = - 1.752, SD = .191)* compared to 150 unit displacement *(Mean = - 3.619, SD = .140)*. Furthermore, there was also a significant difference in estimation scores found between 100 and 150 units of displacement, $p < .001$, ($\eta^2 = .442$), indicating that estimation scores were more accurate when the hand was displaced 100 units (*Mean = - .198, SD = .096*) compared to when it was displaced 150 units (Mean = - 3.619, SD = .140). A significant effect of group was also found, $F(2, 28) = 202.17, p < .001$ ($\eta^2 = .878$), indicating that the HfA group had lesser displacement errors *(Mean = - 0.67, SD= 0.201)* compared to the control group *(Mean*

= *- 3.04, SD = .201)* in estimating the location of the right index finger. However, there was no significant interaction found between groups and hand displacement, $F\ (2, 28) = .035, p = .958$. (Figure 7.4)

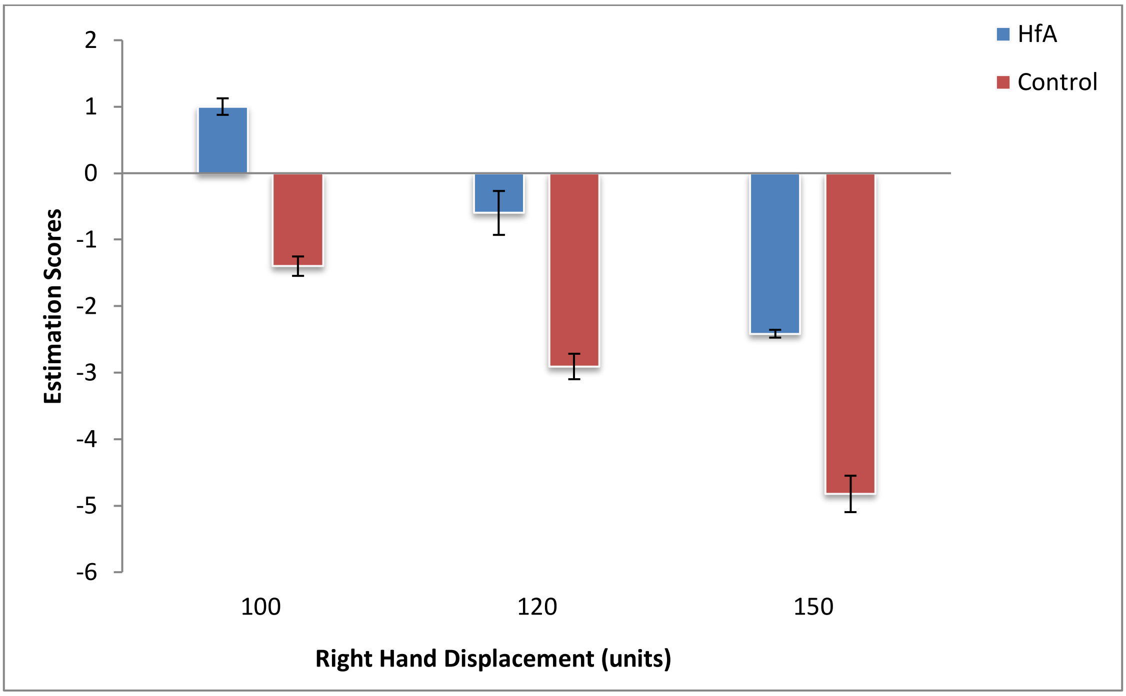


Figure 7.4 Graph representing the average estimation scores achieved by the HfA (blue bars) and control (red bars) across all three hand displacements after following a 25 seconds adaptation procedure. Statistically significant differences were found between groups for all three displacements.

(i) Displacement 100 Units (7.5 cm):

A 2 (Groups: HfA vs Control) x 3 (Conditions: Congruent seen vs congruent unseen vs incongruent unseen) Repeated Measures ANOVA was run to test for any main effects and interactions between the congruent and incongruent conditions when the hand was displaced 100 units (7.5 cm) from its original location. There was a significant main effect of condition, $F\ (2, 28) = 17.64, p < .001\ (\eta^2 = .387)$, indicating differences in finger displacement errors across conditions. Pairwise comparisons (Bonferroni corrected) revealed a significant difference in finger estimation between congruent seen and congruent unseen conditions, p =

.001, (η^2 *= .373),* indicating that estimation averages were closer to the actual finger point during the congruent seen condition *(Mean = .180, SD = .008)* compared to congruent unseen condition *(Mean = .234, SD = .012).* A significant difference was also found between congruent seen and incongruent unseen conditions, *p = .002,* (η^2 *= .392),* indicating that displacement averages were closer during the congruent seen condition (*Mean = .180, SD = .008)* compared to incongruent unseen condition *(Mean = - .198, SD = .096).* Furthermore, there was also a significant difference in estimation scores during the congruent unseen and incongruent unseen conditions, *p < .001,* (η^2 *= .515),* indicating that estimation averages were closer to the actual point during the incongruent unseen condition *(Mean = - .198, SD = .096*) compared to the congruent unseen condition *(Mean = .234, SD = .012).* A significant effect of group was also found, *F (2, 28) = 103.85, p < .001* (η^2 *= .788),* indicating that the HfA group had fewer displacement errors (Mean = 0.04, SD= 0.05) compared to the control group *(Mean = - .257, SD = .054)* during the hand localization task.

There was also a significant interaction between groups and conditions, *F (2, 28) = 181.98, p < .001* (η^2 *= .867).* Independent samples post hoc t – tests (Bonferroni corrected) revealed a significant difference in finger estimation scores between groups during the congruent seen condition, *t (2, 28) = - 10.69, p < .001,* (η^2 *= 1.42),* indicating that high functioning autism group (HfA) *(Mean = .095, SD = .026)* had estimation scores closer to the actual position of the finger compared to the control group *(Mean = .264, SD = .056)* during the congruent seen condition. A significant difference was also found between groups during the congruent unseen condition, *t (2, 28) = - 10.68, p < .001,* (η^2 *= .955),* indicating that the HfA group *(Mean = .104, SD = .027)* had estimation averages closer to the actual position compared to the control group *(Mean = .363, SD = .090)* during the congruent unseen condition. Furthermore, there was also a significant difference in estimation scores between groups during the incongruent unseen condition, *t (2, 28) = 12.53, p < .001,* $(\eta^2 = 1.33)$, indicating that the HfA group *(Mean = 1.00, SD = .481)* had estimates closer to the actual finger during the incongruent unseen condition compared to the control group *(Mean = - 1.39, SD = .564)* (Figure 7.5).

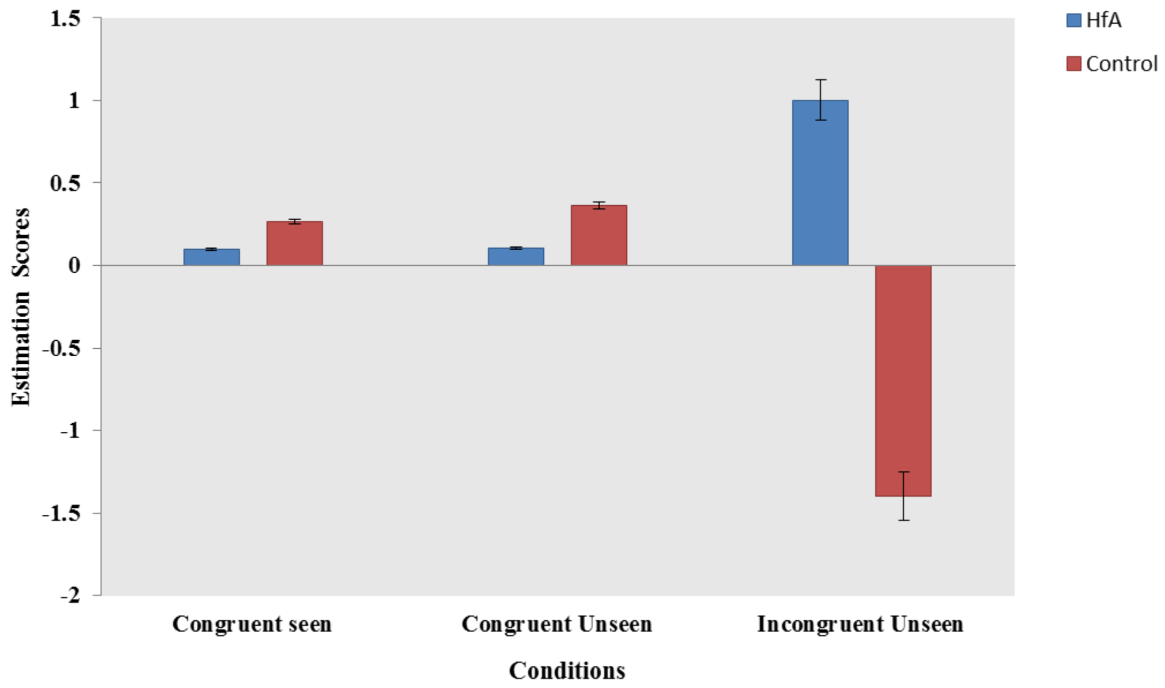


Figure 7.5 Average hand localization task errors in cm for the HfA (blue bars) and control (red bars) groups across all three conditions. Significant differences were found between groups across all conditions. However, both groups made lesser estimation errors during the congruent conditions compared to incongruent unseen conditions.

(ii) Displacement 120 (9.5 cm):

A 2 (Groups: HfA vs Control) x 3 (Conditions: Congruent seen vs congruent unseen vs incongruent unseen) Repeated Measures ANOVA was run to test for any main effects and interactions between the congruent and incongruent conditions when the hand was displaced 120 units (9.5 cm) from its original location. There was a significant main effect of condition, *F (2, 28) = 104.70, p < .001* (η^2 *= .789),* indicating differences in displacement scores between conditions. Pairwise comparisons (Bonferroni- corrected) revealed a significant difference in finger estimation between congruent seen and congruent unseen conditions, *p = .001, (*η^2 *= .756)*, indicating that estimation averages were closer to the actual finger point during the congruent seen condition *(Mean = .180, SD = .008)* compared to congruent unseen condition *(Mean = .234, SD = .012)*. There was also a significant difference in estimation scores between congruent seen and incongruent unseen condition, *p < .001, (*η^2 *= .754),* indicating that estimation scores were closer to actual point during the congruent seen condition *(Mean = .180, SD = .008)* compared to the incongruent unseen condition *(Mean = - 1.752, SD = .191)*. Furthermore, there was also a significant difference found between congruent unseen and incongruent unseen conditions, *p < .001, (*η^2 *= .643),* indicating that estimation scores were more accurate during the congruent unseen condition *(Mean = .234, SD = .012)* compared to the incongruent unseen condition (Mean = - 1.752, SD = .191). A significant effect of group was also found, *F (2, 28) = 24.14, p < .001* (η^2 *= .463),* indicating that the HfA group had fewer displacement errors *(Mean = - 0.133, SD= 0.093)* compared to the control group *(Mean = - .760, SD = .099)* in estimating the location of the right index finger.

There was also a significant interaction between groups and conditions, *F (2, 28) = 43.46, p < .001* (η^2 *= .608).* Independent samples post hoc t – tests (Bonferroni corrected) revealed a significant difference in finger estimation scores between groups during the congruent seen condition, *t (2, 28) = - 10.69, p < .001*, *(η^2 = .402)*, indicating that high functioning autism group (HfA) *(Mean = .095, SD = .026)* had estimation scores closer to the actual position of the finger compared to the control group *(Mean = .264, SD = .056)* during the congruent seen condition. A significant difference was also found between groups during the congruent unseen condition, *t (2, 28) = - 10.68, p < .001, (η^2 = .521)*, indicating that the HfA group *(Mean = .104, SD = .027)* had estimation averages closer to the actual position compared to the control group *(Mean = .363, SD = .090)* during the congruent unseen condition. Furthermore, there was also a significant difference found between groups during the incongruent unseen condition when the hand was displaced 120 units (9.5 cm) from its original location, *t (2, 28) = 6.049, p < .001, (η^2 = .675)*, indicating that the HfA group had scores closer to the actual hand *(Mean = - .598, SD = 1.27)* compared to the control group *(Mean = - 290, SD = .741)* (Figure 7.6)

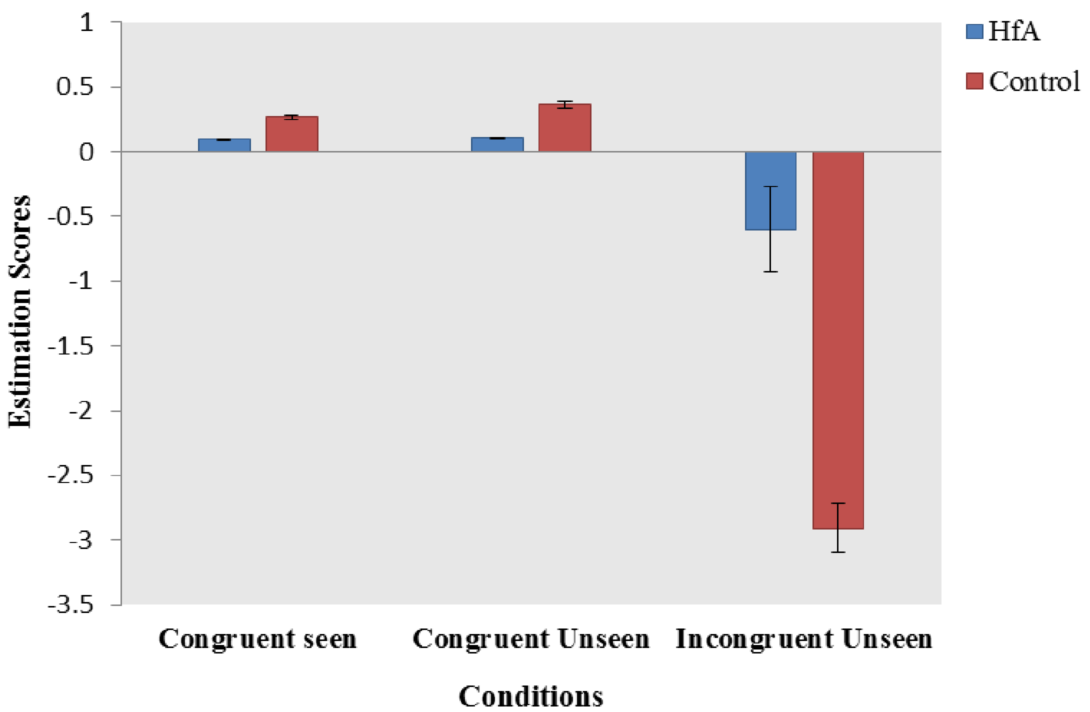


Figure 7.6 Average hand localization task errors in cm for the HfA (blue bars) and control (red bars) groups across the congruent and incongruent unseen condition when the hand was displaced 120 units. Significant differences were found between groups across all conditions. However, both groups made lesser estimation errors during the congruent conditions compared to incongruent unseen conditions.

(iii) Displacement 150 (11.5 cm):

A 2 (Groups: HfA vs Control) x 3 (Conditions: Congruent seen vs congruent unseen vs incongruent unseen) Repeated Measures ANOVA was run to test for any main effects and interactions between the congruent and incongruent conditions when the hand was displaced 150 units (11.5 cm) from its original location. There was a significant main effect of condition, $F(2, 28) = 745.21, p < .001$ ($\eta^2 = .964$), indicating differences in displacement scores between conditions. Pairwise comparisons (Bonferroni- corrected) revealed a significant difference in finger estimation between congruent seen and congruent unseen conditions, $p = .001$, ($\eta^2 = .626$), indicating that estimation averages were closer to the actual finger point during the congruent seen condition *(Mean = .180, SD = .008)* compared to congruent unseen condition *(Mean = .234, SD = .012)*. A significant difference was also found between congruent seen and incongruent unseen conditions, $p < .001$, ($\eta^2 = .602$), indicating that finger estimates were closer to the actual location during the congruent seen condition *(Mean = .180, SD = .008)* compared to incongruent unseen *(Mean = -3.619, SD = .140)*. Furthermore, there was also a significant difference found between congruent unseen and incongruent unseen conditions, $p < .001$, ($\eta^2 = .544$), indicating that estimation scores were closer to the actual location during the congruent unseen condition *(Mean = .234, SD = .012)* compared to the incongruent unseen *(Mean = - 3.619, SD = .140)* condition. A significant effect of group was also found, $F(2, 28) = 48.81, p < .001$ ($\eta^2 = .635$), indicating that the HfA group had fewer displacement errors *(Mean = - 0.738, SD= 0.075)* compared to the control group *(Mean = - 1.398, SD = .075)* in estimating the location of the right index finger.

There was also a significant interaction between groups and conditions, *F (2, 28) = 87.73*, $p < .001$ (η^2 = *.758)*. Independent samples post hoc t – tests (Bonferroni corrected) revealed a significant difference in finger estimation scores between groups during the congruent seen condition, *t (2, 28) = - 10.69, p < .001,* (η^2 *= .551),* indicating that high functioning autism group (HfA) *(Mean = .095, SD = .026)* had estimation scores closer to the actual position of the finger compared to the control group *(Mean = .264, SD = .056)* during the congruent seen condition. A significant difference was also found between groups during the congruent unseen condition, *t (2, 28) = - 10.68, p < .001,* (η^2 *= .401),* indicating that the HfA group *(Mean = .104, SD = .027)* had estimation averages closer to the actual position compared to the control group *(Mean = .363, SD = .090)* during the congruent unseen condition. Furthermore, there was also a significant difference between groups during the incongruent unseen condition when the hand was displaced 150 units (11.5 cm) from its original location, *t (2, 28) = 8.610, p < .001,* (η^2 *= .529),* indicating that the HfA group *(Mean = -2.41, SD = .226)* had estimation scores closer to the actual location of the finger compared to the control group *(Mean = - 4.823, SD = 1.05).* (Figure 7.7)

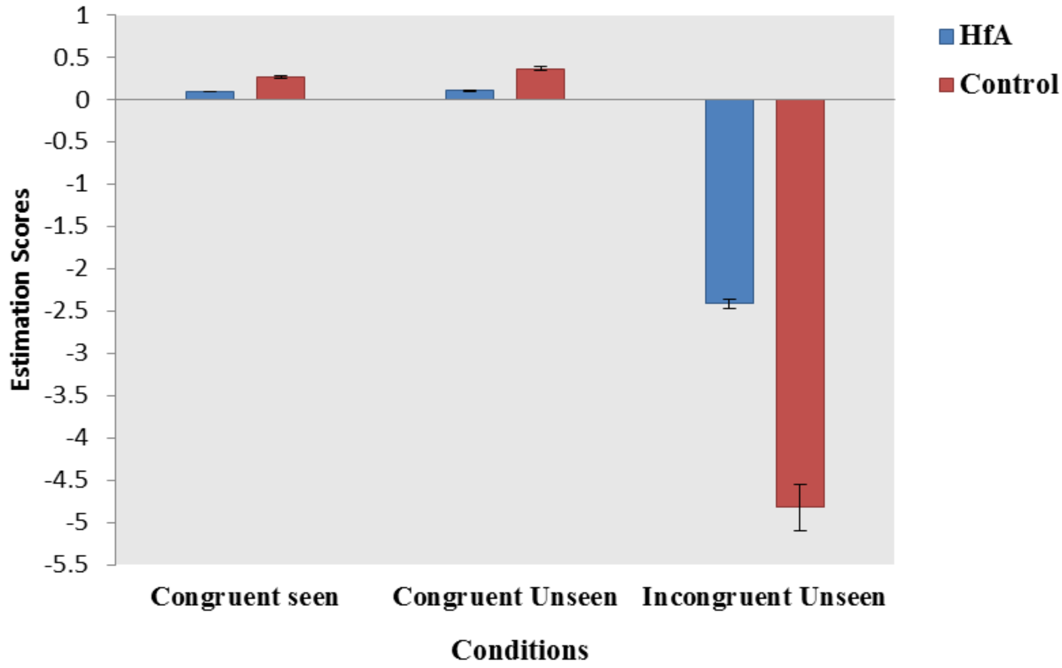


Figure 7.7 Average hand localization task errors in cm for the HfA (blue bars) and control (red bars) groups across the congruent and incongruent unseen condition when the hand was displaced 150 units. Significant differences were found between groups across all conditions. However, both groups made lesser estimation errors during the congruent conditions compared to incongruent unseen conditions.

7.4 Discussion

The current study investigated visuo- proprioceptive integration in individuals with high- functioning autism and an age and IQ matched control group using a hand localization task administered through the MIRAGE multisensory system. In a series of trails, participants were required to estimate the location of their right index finger, with and without visual input and when the hand was displaced to the right to three different locations from its original position after viewing the hand through the MIRAGE screen. It was predicted that both groups, HfA and control, would make lesser amounts of displacement errors in the congruent conditions, congruent seen and unseen. The results gathered support this prediction where both groups made the least amount of displacement errors in the congruent seen and unseen conditions, compared to incongruent unseen conditions. This finding is in line with previous investigations that have used a hand localization task during which participants are more accurate in estimating the location of the hidden limb when both visual and proprioceptive information is available simultaneously and also mimic the results gathered by Bellan and Colleagues (2015) who used a similar procedure.

During the congruent unseen condition, participants were required to estimate the location of their right index finger without any visual input; however, the location of the right hand was congruent to the hand seen through the screen prior to making the estimates. The HfA group showed lesser displacement in estimating the location of the hidden finger, compared to the control group that had significantly more displacement errors, estimating the location to be further to the left of the hidden hand. Compared to the congruent seen condition the HfA group did not have a significant difference in accuracy in estimating the location, however, there was a slight rise in the overall average score for the control group. This can be associated with "estimation compensation" during which participants tend to make estimates a little lesser or higher than intended to compensate for the lack of visual input (Windisch et al., 2007), as during this condition the position of the hand remained in the same location as they had seen in the congruent seen condition, however, visual information was blocked out.

During the incongruent unseen condition, participants were required to perform the finger localization task when their hand was displaced into three different displacements, i.e. 7.5 cm, 9.5 cm and 11.5 cm. An adaptation procedure was used, similar to the one used by Bellan et al., (2015) and one used in the previous study (Chapter 6), however, in the current study participants made estimates regarding their fingertip when their hand was displaced to three different locations and the performance in these conditions were compared to the congruent seen and unseen conditions. Prior to testing it was predicted that the HfA group would make fewer displacement errors (i.e. they would be more accurate) compared to the control group in estimating the location of the fingertip. This was based on the results gathered during the previous study (chapter 6) and the idea suggested by Palmer et al., (2013) that individuals with autism show superior lower- level processing, such as an over- reliance on proprioception, as they are more accurate in reaching for their actual hand rather than the rubber hand during the rubber hand illusion. The results of the current study were in favor of this prediction, as the group differences showed a significant difference in performance between the HfA and control group. Individuals with high- functioning autism made fewer displacement errors on average in estimating the location of the hidden index finger across all conditions, compared to the control group. Between- group analysis indicates that the HfA group had estimates closer to the original location of the hidden fingertip compared to those in the control group. Therefore, providing support for supervisor lower- level sensory processing, whereby, proprioception is given more weightage over vision in the HfA group.

The adaptation procedure lasted for twenty-five seconds during which participants viewed their hands within blue bars which were super imposed on the MIRAGE screen. During this time, the hand was displaced to either 100 units (7.5 cm), 120 units (9.5 cm) or 150 units (11.5 cm) (all participants went through all three displacements using different adaptation procedures) from where they saw their hand before the screen was over laid with a black image to block the view of the participants. Figure 7.4 illustrates the average displacement errors made by the groups when the hand was displaced to three different units. The estimates scores suggest that on an overall level, the HfA group made fewer displacement errors compared to the control group in estimating the location of the hidden right index finger. The diagram illustrates that for both groups, there seems to be a gradual increase in accuracy errors as the distance between the location of the hand last viewed by the participants and where it actually was placed during the three displacements. Average estimates were less when the hand was displaced to 100 units followed by 120 units and the most amounts of errors when the hand was displaced 150 units from its last viewed location. This brings us to another prediction that we made that performance of both groups would get better over trials. However, this was not the case as displacement errors only reduced for the HfA group but not for the control group.

According to previous research (Bellan et al., 2015; Greenfield et al., 2015), it was predicted that over trails and the longer the participants were exposed to the illusion, the performance of the groups would get better, i.e. they would make lesser amounts of displacement errors over trails. However, this was not the case for the current investigation, the TD group's displacement errors showed an increase as the distance between the hands increased and same was for the HfA group. We predicted that over trails the performance of the participants would get better, however, for both groups displacement errors increased as the distance increased but between groups we see a significant difference in performance where the HfA group made estimates closer to the real location of the finger, whereby, the results obtained displayed that the groups estimates switched from the proprioceptive field towards the visual field. This provides us with support for visual influence in HfA. Therefore, giving evidence in support for the visual influence in autism, where individuals with autism do show susceptibility towards illusions but after being exposed to an illusory percept over several trails. For the control group, we expected the performance to get better over trails, however, the results showed that their performance was more influenced by the visual input as the displacement increased. One possible explanation for this could be that increasing the distance makes the task more difficult. Bellan et al's., (2015) study showed that over multiple trails performance got better, however, it is important to note that they used only one displacement (100 units, 7.5 cm) but conducted several trails using the same distance. Therefore, it could be argued that increasing the displacement also increases errors in displacement errors. This would be further discussed in the general discussion considering all the results gathered and how its related to the current sensory integration theories in autism.

According to Bellan et al's., (2015) study, it was suggested that negative average scores were categorized as estimates based on the visual input, whereas, positive values represent a reliance on proprioception. This was because the hand would move towards the right of the screen during the adaptation procedure, whereas, the visual image seen on the screen by the participants was in a different location. If participants made an estimate based on where they saw the hand before the screen was made blank participants would be relying on the visual input, hence, giving averages in the negative values. However, if the participants rely on proprioception they would make estimates on the midline as that represents the original location of the finger. However, if any group over- relies on proprioception, they would have averages above the midline, regardless of the condition. For the current investigation, individuals in the control group had averages of negative values suggesting reliance on visual input. The highest difference in the averages was found for when the hand was displaced 150 units from its original location, increasing the errors in accuracy. The results suggest that as the distance between the actual location of the hand and where it was originally viewed increased, the errors in accuracy increased for the control group. This has also been shown in past research which indicates that participants' accuracy decreases as the distance between the hands increases in virtual reality (Preston, 2013; Longo, 2017). However, for the HfA group, displacement averages were positive during the 100 unit displacement, whereas, there was a switch from the positive estimates to negative during the 120 and 150 units hand displacement. It was hypothesized based on previous research that if individuals with autism tend to over-rely on proprioception than we would have expected accurate estimates from the HfA group regardless of the condition to always be on the midline or in the proprioceptive field. However, this was not found in the results gathered from the current study. Even though, the HfA group was more accurate during the hand localization task compared to the control group, they did not make positive estimations across the trails, which would have indicated an over- reliance on proprioception.

Existing literature suggests that integration of visuo- proprioceptive information regarding the limb position is based on the reliability of the unisensory modality, i.e. vision and/or proprioception, however, visual input usually "dominates" proprioceptive information due to its higher spatial acuity and weightage (Van Beers et al., 1999; Holmes & Spence, 2005). Furthermore, similar mechanisms are reported during the rubber hand illusion in which the visual and tactile integration position overrides proprioceptive knowledge (Botvinick & Cohen, 1998; Kammers et al., 2009). Therefore, similar mechanisms could contribute to the outcome of the current study, where individuals with HfA and those of typical development are relying on the visual input rather than proprioceptive knowledge, such that their estimation during the different displacement conditions are based on location were the hand was viewed last, following the adaptation process. However, this is only during the experimental conditions, but when both visual and proprioceptive information is available, both groups made the least amount of displacement errors. It is also of interest that the HfA group showed a pattern of responses based on proprioceptive information when the hand was displaced 7.5 cm (100 units) from its original location, however, there seems to be a shift from dependence on proprioception to judgements based on visual information as the distance between the hands increased. However, unlike previous investigations that have suggested an over- reliance on proprioception over vision (Palmer et al., 2013; Paton et al., 2012), the current study did not find a similar pattern of behavioral responses.

The current study aimed to investigate visuo- proprioceptive integration in individuals with HfA using a hand localization task requiring participants to estimate the location of the hidden index finger when the hand was displaced into three different locations. The results of the study suggest that both groups were more accurate when the visual and proprioceptive information was available and congruent, and also when the visual input was limited but proprioceptive information was not manipulated (congruent unseen condition). However, both groups showed a tendency to make estimates based on vision regarding the right index finger when visual input was unavailable, proprioceptive information was manipulated and the displacement errors increased when the distance between the hands viewed hand and the original location of the hand was increased. Furthermore, the results showed that compared to the typically developing population in the study, the HfA group was more accurate in estimating the location of the limb which could suggest a strong sense of proprioceptive knowledge but not an over- reliance. Therefore, in conclusion, one could argue that individuals with HfA are equally susceptible as the typically developing adults; however, unlike the TD group the HfA group is much more accurate in localization tasks.

Chapter Eight: General Discussion

8.1. Summary

One of the objectives of this research was to look at the number of non- clinical autistic traits present in a typically developing adult population and to compare their performance on various illusory paradigms. The second objective was to measure the susceptibility of individuals with high and low autism traits towards multisensory illusions through the manipulation of visual, tactile and proprioceptive information using the MIRAGE system in the form of illusion. There is a large body of evidence that suggests visuo- tactile integration in the autistic population is atypical and this type of atypical processing is consistent in those with a high number of non- clinical autistic traits (e.g., Dawson & Watling, 2000; Baron- Cohen et al., 2001a; Baron- Cohen et al., 2001b; De Gelder & Bertelson, 2003; Constantino & Todd, 2003; Foss- Feig et al., 2010; Constantino & Charman, 2012; Cook et al., 2012; Chen et al., 2012; Ronald & Hoekstra, 2011; Robertson & Simmons, 2013; Lundström, 2012; Hames et al., 2014, Hames & Gomez., 2016; Greenfield et al., 2015; Taylor et al., 2020). The majority of the studies available on sensory differences tend to focus on visual and auditory domains, i.e., Cascio et al, (2013) investigated the temporal binding window in children with adults using the flash beep illusion. Hames and Colleagues (2016) investigated cross modal visual and auditory sensory processing in autism using EEG and fMRI and found that in individuals with ASD, combined audiovisual processing is more similar to unimodal processing i.e. they process combined sensory information as individual inputs, compared to neurotypicals. Other studies that have focused on visual and auditory integration processes and have found similar findings using physical tasks as well as questionnaire measures i.e. sensory discrimination questionnaires, (see: Baranek et al., 2006; Cascio et al., 2008; Hames et al., 2016; Williams et al., 2004) to measure prevalence of sensory related concerns in autism.

Studies on typically developing adults with high and low AQ traits have used a variety of different scores to measure autism traits against different illusory percepts (Baron-Cohen et al., 2001a; Ruzich et al., 2015a). They found close similarities between illusion susceptibility amongst individuals with a clinical diagnosis of autism and those with AQ traits. However, for my research I used the original cut-off score of 32 and above to select individuals for the high AQ group and a score of 20 below for the Low AQ group and because recent research using the AQ now suggest that qualitative behavioral similarities are more prominent in individuals scoring higher than 32 on the AQ (Hoekstra et al., 2007; Lundqvist & Lindner, 2017; Ruzich et al., 2015b). Lastly, I compared the performance of individuals with high and low autism traits to those with HfA using various sensory tasks. This was achieved through the use of the MIRAGE multisensory illusion system which enabled me to modify visual, tactile and proprioceptive information using a dedicated software to present participants with realistic sensory illusions limited to the participants own limbs. All groups were presented with three multisensory illusions using the MIRAGE system: (a) the crawling skin illusion (McKenzie & Newport, 2015), (b) the finger stretching illusion (Newport et al., 2015) and (c) the adaptation procedure of the disappearing hand trick (Newport & Gilpin, 2011).

Existing scientific literature examining multisensory illusion susceptibility has provided mixed results, some studies argue that individuals with autism are not susceptible to sensory illusions due to an inability to integrate multiple sources of sensory information (Cascio et al., 2008; Cascio et al., 2012; Foss-Feig et al., 2010; Hense et al., 2019; Ratcliffe & Newport, 2017), whereas, others suggest that they are equally susceptible as their typically developing counterparts, however, they require a larger time period to integrate distinct sensory inputs (temporal binding window hypothesis, Cascio et al, 2012; Greenfield et al., 2016). The rubber hand illusion (Botvinick & Cohen 1998) has ignited research investigating visuo- tactile integration in autism and those with autistic traits of typical development. Research conducted by Baron- Cohen et al., (2001) and Happé (1998) have highlighted that imagination deficits are a core diagnostic criterion for autism and also that they pay particular attention to details. Keeping that in mind, bodily illusions that involve the incorporation of an artificial object such as the robotic arm or the rubber hand could potentially hinder the ability of those with autism as their rigid cognitive style of thinking might affect them to imagine them as their own. Therefore, bodily illusions which require the incorporation of an artificial limb or body part into their body schema might affect their performance during multisensory tasks. Furthermore, a rigid style of thinking, difficulty to incorporate external objects and inflexibility of thought could all be factors contributing towards the inconsistent results, therefore, some studies indicate that individuals with autism are less susceptible to sensory illusions, whereas, other indicate equal susceptibility towards them. However, the current research does not control for all of these factors, one thing that was of highest interest was to understand whether the inconsistent results gathered in the past are mainly due to the inability to accept an artificial object as their own body part. Therefore, to control for this factor, the current research delivered the illusions on the participants own limb eliminating the factors that could contribute towards not incorporating an artificial limb into their body schema in order to see whether individuals with autism will be more susceptible to the illusion when the hand they are seeing is their own.

Moreover, the rubber hand illusion uses mainly subjective ratings, with statements that could reflect personal differences rather than susceptibility towards the illusion. The RHI involves participants reaching for their hidden hand after the rubber hand has been given ownership. Therefore, I investigated to see if a more dynamic illusion is presented to the participants own hand could generate different results. Measuring illusion susceptibility and ownership with the use of subjective measures means there is a high risk of individual differences in ratings. Therefore, to further extend and understand the differences that have been shown in previous research (Palmer et al., 2013; Paton et al., 2012; Piven et al., 1997), I have used an estimation task where participants were required to make judgements regarding their index finger and a hand localization task in order to further understand whether differences in susceptibility are due to individual biases or because there is indeed lesser embodiment of the illusion in the autistic populations or whether individuals with autism and those with high autism traits equip a more context dependence rather than integrating concurrent sensory information.

Bahrick et al., (2018) states that issues with multisensory integration, regardless of any specific sensory modalities, could underlie the many sensory and social behaviors that constitute autism as a disorder. Understanding the underlying differences could provide us with a lot more information on how sensory integration works in individuals with autism. This can help us in establishing and designing interventions that could facilitate learning and the quality of life of children and adults on the autistic spectrum. It is often the case that when testing clinical populations, it is difficult to gather high number of participants due to various reasons. Therefore, if behavioral and sensory similarities do exist between individuals with autism and those on the spectrum but of typical development; it can help us test larger groups and understand baseline differences, before implementing the same strategies on individuals with autism. The current thesis has three main aims 1) understanding and measuring illusion susceptibility of those with high and low autism traits and HfA, 2) whether there is a similar pattern of susceptibility between those with high number of autism traits and adults with a diagnosis of HfA and 3) to understand whether reduced illusion susceptibility is due to differences in experimental design or whether individuals with HfA are less prone to the illusory effects of the illusion because they embody the illusion less, due to either reduced visuo- tactile integration or an over- reliance on proprioception. However, it is important to note that it is beyond the scope of the research presented in this thesis to understand the exact mechanisms underlying susceptibility differences and what causes these differences in illusion susceptibility. I will now summarize my experimental findings chapter by chapter and examine how these findings may contribute and correspond with the existing literature on illusion susceptibility in individuals with autism traits and those with HfA.

8.2. Multisensory Sensory Illusion Susceptibility across the Autistic Spectrum

8.2.1. The crawling skin illusion in individuals with high and low autism traits and high-functioning autistic adults

In chapters 2 and 3, I investigated the susceptibility of adults with non- clinical autistic traits and those with HfA towards the crawling illusion (McKenzie & Newport, 2015). During this illusion participant were required to place their right hand within the MIRAGE setup and view their hand through a screen in three different conditions. This illusion has been previously used in individuals with MUS like traits (McKenzie & Newport, 2015) in order to examine whether there is an over- reliance on top- down knowledge regarding their own limb. I used this illusion to examine if there is an effect of visual distortion of their own right hand in individuals with high and low autism traits and those with HfA and also as a way of measuring how much ownership individuals with HfA give to their own virtual hand, as previously it has been shown that illusions involving the in- cooperation of external body have demonstrated that individuals with autism tend to not give ownership. This includes bodily illusions such as the full- body illusion, the famous rubber hand illusion and also the robotic arm illusion (Paton et al., 2012, Palmer et al., 2013). Furthermore, this illusion was also used to examine the influence of visual information in participants with autism traits and those with HfA.

In experiment one (Chapter 2) typically developing adults, with high and low autism traits (as measured through the AQ; (Baron-Cohen et al., 2001a)) were subjected to three visual conditions and after each condition participants rated their illusion experience verbally on a 9.0 rating scale. Three set of sets of measures were used (1. Hand ownership, 2. Somatosensory sensations and 3. Control statements) for which the ratings were collected and each sets of ratings were averaged to obtain a mean ownership, somatosensory and control average score. During the veridical (baseline condition) there was no significant difference in ownership ratings from both high and low AQ groups, as both groups rated high ownership over their own digitally presented hand. Similarly, during the darkened condition (control condition for the experimental condition) both groups had high ownership scores with no significant difference. In the experimental condition, where participants viewed their hand in static or fuzzy state, there was a significant drop in ownership for the low AQ group, meanwhile the high AQ group still had high ownership scores. In the non- somatosensory ratings (control statements) no significant differences in the average ratings given for the control statements by participants in the high and low AQ groups. Somatosensory ratings were of the most importance here, as it is suggested that moving pixels superimposed on the participants digitally presented hand causes tactile sensations in the absence of any physical tactile input (McKenzie & Newport, 2015). The highest variation in terms of ratings between the groups was found during this condition, where the high AQ group had an average of score of 2.8/ 10 across the three conditions, disagreeing with feeling any sort of somatosensory sensations. On the other hand, the low AQ group reported feeling lesser somatosensory sensations during the veridical and darkened conditions, but had an average score of 7.5/ 10 reporting the experience of visually induced sensations during the experimental condition (crawling skin condition). This can be attributed to the effect of visual information over-riding the cognitive knowledge regarding one's own hand. The results indicate that the visual influence for the low AQ group is higher compared to the high AQ group, that seems to be reporting no visually induced sensations.

Experiment two (chapter 3) was a replication of experiment one, however, instead of participants with high and low autism traits, individuals with HfA and age/IQ matched control participants were subjected to the illusion. In order to streamline the process, the illusionary ownership questionnaire that was used in study 1 was kept the same, however, the rating scale was changed from 1 to 9 to -3 to + 3. This modification was made to ensure that participants with HfA are not confused with all positive values, therefore, negative numerals were associated with disagreement and positive with agreement. In terms of ownership, the HfA group had high ownership across all the three conditions with no significant differences amongst their scores; however, the control group had lower ownership scores in the crawling skin condition, which is similar to the results from, experiment one. There were no significant differences found between the HfA and the TD group, as both groups had negative ratings in the control statements indicating that participants were paying attention while rating the statements. During the experimental condition, no significant difference in visually induced tactile sensations was found for the veridical condition between groups. There was a significant difference found between groups during the darkened condition, however, both groups ratings were within the negative range indicating disagreement with the statements. This difference can be attributed to changes that the darkened condition produces. Unlike the experimental condition, during the darkened condition the contours of the hand are blurred making it look like the hand has been merged with the MIRAGE surface. Therefore, this change in the appearance of the hand can be attributed to the difference found in the darkened condition. It is a common finding and Newport and McKenzie (2010) have also reported an effect of darkness in their study. For the crawling skin illusion, a stark, significant difference was found between the HfA and TD group, where the HfA group reported no somatosensory sensations, but the TD group reported feeling high levels of visually induced somatosensory sensations.

All groups (high and low AQ; HfA and TD) gave ownership over their own digitally presented hand presented through the MIRAGE system. This tells us that MIRAGE (Newport et al., 2010), might serve as an alternative tool to investigate bodily ownership in individuals with autism. This is important in context of autism because illusions which involves an individual to incorporate any external object, such as the robotic hand illusion or the mannequin illusion, whereby, participants give ownership to a fake body tend to show greater difficulty in doing so (Tsakiris, 2010) and it has been suggested that only once ownership is established, one can experience the illusion (Newport et al., 2010; Ramakonar et al., 2011; Tsakiris, 2011). One of the many deficits that comprise HfA as a disorder is an imagination deficit. The largest variation in ratings was found during the experimental (static hand) condition. Both High AQ group and the HfA group reported feeling no somatosensory sensations compared to the low AQ group as the TD groups, which seemed to being influenced by the visual distortion (suggesting movement) on the hand. Past research has put forth mixed findings, some studies suggest that visual distortions do not hinder participants from giving ownership to an artificial object, i.e. such as a wooden hand (Kalckert & Ehrsson, 2014) and even to a wooden block (Armel & Ramachandran, 2003), to giving ownership to a hand that is different in size, texture or shape (Kalckert & Ehrsson, 2014 & Ramakonar et al., 2011). On the other hand, we have studies that have used the RHI paradigm and other bodily illusions in the healthy population and have found a positive correlation between the physical appearance of the real hand and the dummy hand, indicating that participants are more likely to succumb to the illusion if the artificial hand and the real hand have similar physical attributes (Lloyd, 2007; Peck et al., 2013) and other studies suggest that color and texture plays a critical role in giving ownership towards an artificial hand i.e. participants who are Caucasians are less likely to give ownership to a black hand (Lira et al., 2017; Farmer et al., 2012). However, most of these studies have been conducted with participants with no learning or developmental disabilities., therefore, it can be argued that individuals with autism might employ different mechanisms and how aforementioned factors influence body ownership. However, a study by Ratcliffe & Newport (2017) has demonstrated using the MIRAGE system how simple visual distortions can effect hand ownership. Therefore, in the context of the current study, visual distortion of the hand seems to be playing a part and this distortion of the hand is further amplified when an individual start's feeling sensations that does not have any tactile sensory source. For example, in the current study, visual information indicates/ creates conflicts with the knowledge regarding the hand, however, the illusory sensations are being felt, yet the visual information cannot find a physical source for it. Hence, manipulating an individual's own contextual knowledge. This finding in particular provides further support for the dominance of visual information over other senses and pre- existing knowledge one has about their own limbs (Touzalin-Chretien et al., 2010). However, no reports of somatosensations by the high AQ group and the HfA group could indicate that these individuals do not rely on the visual input as much as the typical population does. As suggested earlier, it has been indicated that individuals with high autism traits and HfA rely more on a single sensory source, which is often tactile input (as it has been shown in studies measuring visuo- tactile discrimination (Daprati et al., 2018; Riquelme et al., 2016). Therefore, it can be argued that during this condition, the effect of visual information is reduced in this group because of the missing incoming tactile information which is contradicting the visual information that no such tactile sensations are present. As suggested earlier, in a trade-off between visual and tactile information, individual's with autism tend to be hypervigilant towards tactile information, therefore, it could be the case that missing physical sensations on the hand is resulting in individuals with autism to be less likely to report the somatosensory sensations during the static skin condition.

Both experiments investigated the effects of visual information on tactile perception in autism and those high autism traits and the results were highly comparable between the two groups. It is only the Low AQ group and the typically developing comparison groups that were sensitive to the contextual cues of the illusion and these cues modulated the interpretation of somatosensory information emanating from the hand. However, due to the novelty of the task it is unclear whether the somatosensory effects reported by the low AQ group and the TD group is because of the misinterpretation of the signals received (illusory effects) or due to the visual capture overriding pre- existing knowledge regarding the limb (Hay et al., 1965; Holmes & Spence, 2005; Leekam et al., 2007). However, it is clear is that the high AQ group and individuals with HfA were unaffected by the visual context and retained high ownership of their limb across all conditions, which is interesting as previous research using other bodily illusions has not reported high ownership in a similar population (Cascio et al., 2008; Foss-Feig et al., 2010; Palmer et al., 2013; Paton et al., 2012; Piven et al., 1997) (See figure 8.1 below for a summary of the results).

An alternate interpretation of the outcome of the study could be explained under the idea of "expectance" (Rief et al., 2015). In general, viewing moving pixels on one's hand would generate an expectation that something should be felt as the visual input suggests this to be the case. These signals are internal and are not modulated by any external physical stimuli. Therefore, the conflict between what's been viewed (external information) and the internal representation of the hand could compensate to match the reality. The expectancy bias theory has been previously been investigated in the typically developing population in reference to negative and positive stimuli and in reference to face processing (Proulx et al., 2017). However, if this were the case we would have seen a rise for somatosensory scores during all the conditions, regardless of the group. But as the results suggest this was not the case for the current study as we did find an effect for the control group. Also, if this were the case, we would have seen variations in the control (non- somatosensory) statements as well, but no such reports were recorded. Therefore, the crawling skin illusion seems to be working for those with low autism traits and of typical development as the visual information is enough for these participants to report the visually- induced sensations, however, for those with high autism traits and HfA this mechanism does not seem to work. This could either be due to visual information not impacting the cognitive knowledge regarding the hand or it could be because these individuals have been shown to be hypervigilant to tactile information (Eliane et al., 2015; Mikkelsen et al., 2018), therefore, not reporting any sensations.

Conditions	Groups	Ownership Ratings	Somatosensory Scores	Control statements
Veridical (baseline)	High AQ	Yes	No	No
	Low AQ	Yes	No	No
	HfA	Yes	No	No
	TD	Yes	No	No
Darkened	High AQ	Yes	No	No
	Low AQ	Yes	No	No
	HfA	Yes	No	No
	TD	Yes	No	No
Crawling Skin	High AQ	Yes	No	No
	Low AQ	No	Yes	No
	HfA	Yes	No	No
	TD	No	Yes	No

Table .8.1. Summarizing the main findings obtained from the static hand illusion across the Autism spectrum. Yes = positive/ high scores and No = negative/ low scores. This table has been provided to illustrate the main findings to aid in the understanding of the reader. For detailed results refer to results chapter 2 and 3.

8.2.2. The Finger Stretching Illusion in individuals with high and low autism traits and HfA

Given that both groups, TD group with high and low autism traits and those with HfA gave ownership to their own virtual hand, I then used a more dynamic illusion that involves the interplay of visual, tactile and proprioceptive information. The finger stretching illusion (Newport et al., 2015) was presented to participants of typical development with high and low autism traits and those with HfA against an age/ IQ- matched control group. During the finger stretching illusion live video image of participants own right index finger was visually stretched using a software delivered through the MIRAGE. The illusion works in a way that the experimenter grasps the tip of the participants' fingertip and gently tugs on the end while the video image of the index finger is viewed as being stretched. This is a highly compelling illusion as the synchrony between what is being felt and what is being seen is simultaneous and has been recently used in a very large sample (Newport et al., 2015) and it provides us with a clear distinction between the top- down and bottom- up processes being employed during the illusion.

In experiment three (chapter 4) high AQ and low AQ scorers went through the finger stretching illusion. The experimental condition was paired with a baseline condition where no manipulation was applied, a visual condition and a tug (only tactile input) condition, the baseline condition was used to compare performance in the subsequent conditions. Results were gathered using an illusionary experience questionnaire and objective measures were taken to further confirm whether participants were embodying the illusion. No significant differences in ratings given by participants in both groups for the control statement were found. This was expected as the illusion had no effect on the temperature of the participants hand. For the ownership statement, results showed no significant differences between the high and low AQ groups. Similar was the case for the tug condition, where both groups displayed high ownership over the digitally presented finger. During the visual condition, where the virtual finger was "visually" extended without any tactile input, the results revealed a significant difference in ownership ratings between groups, where the high AQ group retained ownership of their virtually extended finger, and the low AQ group lost ownership over their extended finger. An explanation for this could be explained under the context of visual distortion and loss of ownership, a finding that was found during the static hand illusion where individuals in the low AQ group lost ownership over their own hand when it was presented in a fuzzy/ static state. This has also been demonstrated before where changes in the size, shape or texture of the limb has led to loss of ownership over ones hand (Newport & Preston, 2010; Schauder et al., 2015b). Also some studies have shown a positive correlation between ownership and visual appearance for not only limbs but also faces, where participants gave higher ownership scores to their own faces and limbs when there was higher resemblance (Chevallier et al., 2015; Churches et al., 2010; Gelder et al., 1991). Furthermore, during the synchronous stretch condition (experimental condition) both groups gave high ownership over the stretched finger. This is not surprising as this is a common finding during the finger stretching illusion (Newport et al., 2015). For the statement measuring illusion susceptibility, no significant difference was found during the baseline condition, the visual stretch condition and the tug conditions between the high and low AQ groups. A slight difference was found during the visual condition; however, this difference was within the negative values, indicating disagreement but to different levels. Furthermore, this difference can also be attributed to the fact that individuals did indeed feel like their finger was longer as the visual distortion could have affected their judgements. Whereas, seeing their own finger being visually stretched could cause a conflict between one's own knowledge and what one is seeing. Therefore, according to the expectancy theory (Rief et al., 2015), if the sensory information, i.e. in this case the visual stretch, is stronger, participants are more inclined to report it as an actual sensation. What was of highest interest was the difference in the synchronous stretch condition. The high AQ group disagreed with the statement measuring illusion susceptibility, whereas, the low AQ group was extremely susceptible to the illusion as shown by the high number of ratings scores. Furthermore, as a control for the estimation task, participants were required to make estimates regarding the perceived location of their knuckle; no differences were found for this measure indicating that participants understood the task at hand and that the effect of the illusion is only limited to the finger and not the knuckle.

Previously, studies have used subjective ratings as a measure of illusion susceptibility (McCauley & Henrich, 2006; Palmer et al., 2013; Paton et al., 2012; Ramakonar et al., 2011), however, when measuring embodiment using multimodal illusions, subjective ratings can be prone to biases (Elam et al., 1991; Merchant et al., 2010; Moers, 2005). In order to examine if variation in subjective ratings reported in existing literature measuring performance in the autistic population were simply because of biases, I used an estimation task that followed each condition after the manipulation was applied to the fingertip. This task was fairly easy as participants were required to estimate the perceived location of their fingertip in all the conditions. There were no significant differences found in estimation scores between groups during the baseline condition. A significant difference was found between groups during the visual condition, where the low AQ group's average score was 40 percent further from the actual location of the fingertip. During the tug condition, a significant difference was found between groups, indicating that the high AQ group had estimates closer to the actual location of the fingertip. The increase in estimation scores during the visual and tug conditions will be discussed along the results of the next study. As predicted, the largest difference in estimation scores was found during the synchronous stretch condition (experimental condition) during which the estimates of the low AQ group were closer to the visually stretched finger, whereas, the high AQ groups estimation was closer to the location of the actual fingertip.

In Experiment four, I used the same methodology as Experiment four to investigate the susceptibility of individuals with HfA and an age/ IQ- matched control group towards the finger stretching illusion. The results demonstrated no significant differences for the control statements between the HfA and the comparison group, as both groups disagreed with the statement measuring temperature change in the finger. This was used as a control because the illusion does not elicit temperature changes in the limb. Illusion ownership scores did not reveal a significant difference in ownership ratings during the baseline condition between groups, both groups had high ownership scores. A significant difference in ownership scores was found for the visual condition, where the HfA group had positive scores (accepting ownership of the visually stretched finger), whereas, the comparison group lost ownership over their own visually stretched finger. This finding is consistent with that of the previous experiment, in which individuals with lesser autism traits lost ownership of their finger when it was visually stretched. This again, is a common phenomenon whereby visual changes to the body could alter one's perception of their own body (Rief et al, 2016). No significant differences were found between groups during the tug condition, as both groups had high ownership scores. This condition is similar to the baseline condition as no visual manipulation is applied that alters the size of the finger, however, participants just view the experimenter gently grabbing the tip of the finger and giving it a tug. For the synchronous stretch condition, no significant differences in ownership ratings was found between the HfA and control groups. As mentioned previously, knuckle estimates did not generate a significant difference between groups indicating that participants understood the task.

In terms of illusion strength ratings (subjective measure of illusion susceptibility), no significant difference was found between groups during the baseline condition, visual condition and the tug conditions. Both groups disagreed with the statement measuring susceptibility, however, there were differences in the level of disagreement which can be attributed to individual differences in responses. Such that, similar to the previous investigation, the variation in scores can be attributed to the effect of the visual stretch and also, especially in the case of the HfA group and how literally they took the statements during each condition. This finding in particular shows us how the wording of statements can have an effect on the responses gathered during experiments. This will be more elaborated in the limitations of these studies. During the synchronous stretch condition, a significant difference in illusion strength ratings was found, where both groups rated positive scores to the statement measuring susceptibility. This finding is not consistent with that of the previous study, where individuals with high AQ scores disagreed with the illusion susceptibility statement. Variations in subjective ratings have been found in various other studies, such as those done using the rubber hand illusion and the robotic arm illusion, where some studies have found high susceptibility ratings (Cascio et al., 2008; Cascio et al., 2012) whereas others have reported lower susceptibility ratings (Palmer et al., 2013; Paton et al., 2012). Therefore, in order to remove this inconsistency and understand this better, the current study required the participants to make objective judgements in order to confirm their subjective ratings. Both groups did the estimation task after the ratings were collected. The results showed that, during the baseline condition both groups estimates were closer to the location of the actual fingertip; however, the HfA group was significantly closer to the actual location of the fingertip. During the visual stretch condition, the HfA group was close to the real location of the finger, whereas, the comparison group's estimate was closer to the location of the visually stretched finger location. This difference, whereby, we see that the control group's estimates are higher during the visual stretch condition could be attributed to the conflict that has been created between a person's top- down knowledge regarding their own finger and watching their finger being stretched in real- time. We have already seen that vision on its own plays a crucial role in impacting one's knowledge regarding their own limb and body parts, therefore, the effect of visual information alone has been a consistent finding throughout this research. Previous studies that have used similar paradigms have found similar results, whereby, visual information by itself has been shown to be sufficient enough to cause overestimations (Buckingham & Goodale, 2010; Newport et al., 2015; Ratcliffe & Newport, 2017). During the tug condition, the HfA groups' finger estimates were closer to the actual fingertip, whereas, the estimates made by the comparison were higher than that of HfA group. During the synchronous stretch condition, the difference in estimating the location of the actual finger was quite large. The HfA groups estimates were closer to the location of the actual fingertip, however, the comparison groups estimates were much closer to the stretched finger, even more so than the estimates made during the visual condition.

Three main patterns emerged, first that the synchronous stretch condition produces the strongest illusory effect. This is consistent with a previous study that found finger stretching illusion produced positive results in the majority of the participants who took part (Newport & Preston, 2010; Newport et al., 2015). Secondly, the results of this study combined with those of the previous chapters, it is apparent that both the HfA group and the typically developing high AQ scorers are susceptible to the illusion when only visual manipulation is applied. This can be attributed the effect that visual manipulation to one's own body can impact judgement which is related to the dominance of visual information over the other sensory information. Thirdly, the results of this study show that illusion susceptibility can vary depending on task expectations and personal biases especially when using a numerical scale. Subjective ratings can tell us very little about embodiment of the illusion, especially when using multimodal illusions. The results of experiment 3 and 4 indicate that unlike those with low AQ scores and typically developing adults, individuals with high AQ scores and those with a HfA do not embody the illusion in the same way as those of typical development. This could explain the variations in subjective ratings found using other bodily illusions (Palmer et al., 2013; Paton et al., 2012; Schauder et al., 2015b). Furthermore, this supports the original mechanisms put forth by Tsakiris and Haggard (2005) suggesting that only once the illusion has been embodied through ownership one would experience the effects of the illusion. On the other hand, it can be suggested that the variations in the results found during the rubber hand illusion and other multisensory illusions used in the autistic population could be due to embodiment issues. If the autistic population does not embody the illusion, they will not experience the illusion. For example, the judgements made by the HfA group were closer to the location of their actual fingertip and this was due to lack of embodiment of the illusion. Whereas, the low AQ group and typically developing adults were highly influenced by the synchronous visual and tactile information and that it influenced their knowledge regarding the fingertip. On the other hand, one could also argue that the reason why the HfA group made estimates closer to the actual location of the fingertip was because the visual and tactile information was not influencing their judgements, however, the proprioceptive feedback was overriding the other sensory inputs. This would explain why individuals in the HfA group were better at estimating their finger location during all the conditions. Furthermore, it has also been argued that proprioception is considered as an internal sense, whereby, even though it is modulated by touch, it can be activated on its own. Therefore, if someone is hyperaware of their internal functioning, one would be better at using internal senses (Boyd et al., 2009, 2010; Calder et al., 2015; Elwin et al., 2012; Murray et al., 2005; Schauder et al., 2015b). Furthermore, hyper-awareness of internal senses (such as proprioception) is often reported in autism and in order to test this, we designed the next two studies to measure visuo- proprioceptive inputs. (See table 8.2 for a summary of the main findings).

Conditions	**Groups**	**Ownership**	**Illusion Strength**	**Objective Measure**
Baseline	High AQ	+	-	++
	Low AQ	+	-	++
	HFA	+	-	++
	TD	+	-	++
Visual Stretch	High AQ	+	-	++
	Low AQ	-	-	--
	HFA	+	-	+
	TD	-	-	--
Tug (no Stretch)	High AQ	+	-	++
	Low AQ	+	-	--

	HFA	+	-	++
	TD	+	-	++
Synchronous Stretch (visual + tug)	High AQ	+	+	++
	Low AQ	+	-	--
	HFA	+	+	+
	TD	+	+	--

Table 8.2. Summarizing the main findings from the finger stretching illusion in the High and low AQ groups and those with HFA and typically developing individuals. + = represents ownership given or positive ratings to the illusion susceptibility measure. - = represents dis-ownership or negative ratings to the illusion susceptibility measure. ++ = indicates estimates closer to the real finger. -- = indicates estimates closer to the visually stretched finger.

8.2.3. Susceptibility to Disappearing hand illusion in individuals with high and low autism traits and high- functioning autistic adults

Over- reliance on proprioception is one of the more recent theories which tries to explain why individuals with autism are better at the hand location task during the rubber hand illusion (Botvinick & Cohen, 1998; Kammers et al., 2009; Palmer et al., 2013; Paton et al., 2012). This theory argues that individuals with ASD show superiority over modal specific information, such as proprioception, and a reduced processing of multimodal modal inputs, such as visual tactile synchrony. This has been used to explain why individuals with ASD are less prone to the visual tactile synchrony when going through the bodily illusions and their estimates are closer to their real hand as opposed to the rubber hand. Also, in line with the results presented till now we see a trend where the HfA group is significantly better at estimating the location of their limb/ finger, while simultaneously over- riding the visual-tactile inputs. Furthermore, it has also been argued that individuals with autism show superior interoceptive abilities than the typically developing counterparts (Schauder et al., 2015b).

A study by Schauder and colleagues (2016) found that the autistic group was much more aware of their internal heartbeats, as opposed to the typically developing population. Higher awareness of internal cues rather than external cues could explain why individuals with ASD are better in tasks involving proprioception and at the same time this internal focus could be detrimental in everyday social functioning. The previous experiments in this thesis used both subjective and objective measures to measure illusion susceptibility, ownership and embodiment. Individuals with HfA and those with high autism traits are superior at hand localization tasks even during the experimental conditions compared to the typically developing group, however, it is only the low AQ group that lost ownership and overestimated the location of their perceived fingertip only when visual manipulation was applied. In order to understand this difference further, the following two experiments looked at how individuals with high autism traits and those with HfA would perform during an illusory paradigm that involves the manipulation of visual and proprioceptive information[15].

Experiment five (chapter 6) asked high AQ scorers and low AQ scorers to perform a hand localization task using the MIRAGE system in order to investigate the effects of visual and proprioceptive inputs. Participants were required to make judgements regarding the location of their right index finger in seen and unseen conditions following a brief adaptation procedure. [16]Statements pertaining to ownership of the hand as viewed through the screen resulted in no significant differences between groups, as both groups gave high ownership to

[15] Proprioception is the sense through which we perceive sense and movement in our body. It is considered as a sixth sense. Previous research has stated that visual and proprioceptive input together leads to better proprioceptive performance, hence, its implications towards establishing typical perception.
[16] Acclimatization statements- these were not used as a part of the analysis

their digitally presented hand. The localization task results indicated that the least amount of errors made by the groups was during the congruent seen condition (CSC) followed by the congruent unseen condition (CUC) and the most amount of localization errors were reported during the incongruent unseen condition (IUC). Both groups made the least amount of errors during the CS condition as during this participant could view their hands, therefore, both visual and proprioceptive information was congruent. In the CUC condition, the location of the hands remained similar to the previous condition, however, the visual input was blocked and participants relied on their existing knowledge regarding their finger location to make judgements which is why there was a slight increase in errors as shown by the results obtained. However, during the experimental condition, when both visual and proprioceptive information were incongruent, participants made the most amounts of errors. This could be the result of the mismatch between the existing knowledge regarding the hand where it was last seen and participants relying on their proprioceptive information. The diagram below illustrates these results, whereby, positive scores represent individuals making judgements based on their proprioceptive inputs, whereas, negative estimation scores meant that individuals are relying on the visual input, hence, making estimates based on where they saw their hand last. It is evident that in seen conditions, participants from both groups were more accurate. This can be attributed to the fact that both visual and proprioceptive information are co-current and even when the visual input is no longer giving feedback; estimates are based on prior knowledge regarding the hand location and the proprioceptive feedback. However, both groups have made the most amounts of errors when the visual information and proprioceptive information are manipulated. Both groups have a negative average score indicating they are relying on the information provided by the visual input prior to the input being blocked. What is of interest here is that even though both groups had a negative average score in estimating, people with high autism traits made significantly fewer errors compared to the low AQ group. However, the results of this study do not indicate that individuals with high autism traits rely more on proprioception rather than other sensory modalities because if there was an over-reliance on proprioception one would expect average positive scores. Therefore, the results indicate that both groups display reliance on visual input rather than proprioceptive information. However, as a whole, result do indicate that lesser displacement errors were made by the high AQ group as their estimates were close to the midline.

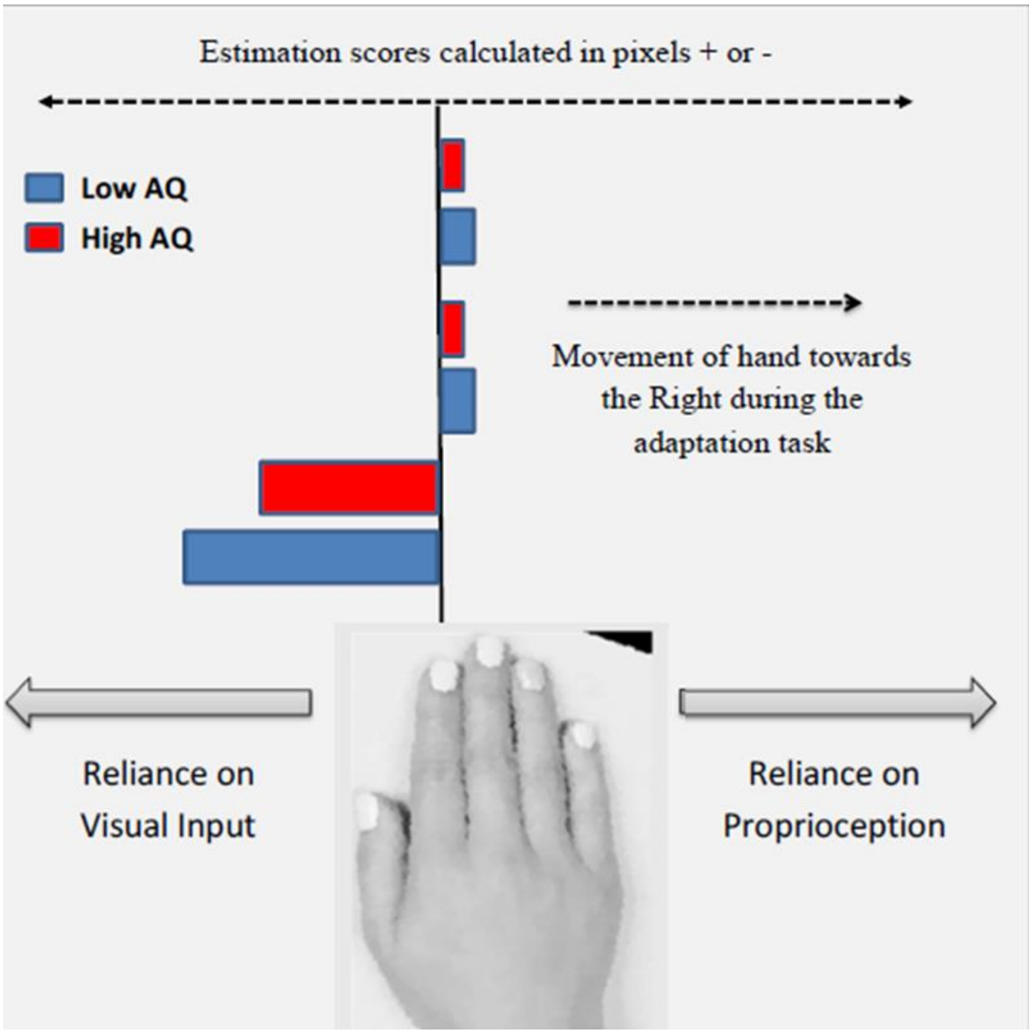


Figure 8.1 shows a diagrammatic image of the task used in experiment 5 and 6. *This image is not to scale

Experiment six was a replication of experiment 5; however, one methodological change was made to further investigate the reliance on proprioception and interoceptive abilities in individuals with HfA. During the incongruent unseen condition, before the hand localization task, each participant went through an adaptation procedure during which the hand of the participant drifted away from its original location. In the previous study only one displacement was used, however, in this investigation three different displacements were used (100 units, 120 units and 150 units) in order to investigate (a) whether individuals with autism indeed are “superior” at proprioceptive processing, (b) if the amount of displacement between the real hand and the virtual hand influences judgements and (c) if over trails the performance of the participants gets better. This modification was also made in regards to the findings of Bellan et als., (2015) study which indicates that one would expect a gradual drift from proprioceptive reliance to visual input in the typically developing population. Similar to the previous study, acclimatization scores found no significant differences between groups indicating that both groups gave ownership to the hands as viewed through the MIRAGE screen. There was a significant difference found in estimation errors between groups during the congruent seen and congruent unseen conditions, however, the HfA group estimates were much closer to the actual location of the finger compared to the control group who on average made more displacement errors. For the experimental conditions, three different displacements were used to measure hand localization during the incongruent unseen condition. When the right hand was displaced 100 units (7.5cm) from its original location during the adaptation task, the HfA group had an overall positive estimation score negating that participants estimates were reliant on proprioceptive inputs instead of relying on the visual information related to the location of the hand last seen. However, this is not found for the control group as their average estimation scores were negative, therefore, relying more on visual input in estimating the location of the hand based on knowledge regarding the location of where they saw their hand last before the visual input was blocked. When the displacement between the location of the unseen hand and where it really was increased, both groups had negative average estimation scores indicating that both groups could be using their visual knowledge in order to estimate the location of the finger. Even more so, when the distance is further increased (150 Units) during the adaptation task, the results indicate that both groups made more displacement errors, again indicating that visual knowledge regarding the hand location is affecting their judgements. It is interesting to note that individuals with HfA showed a more proprioceptively driven judgements during the first displacement, however, as the distance between the hands increased there was a switch from the proprioceptive to the visual field. This finding in particular is in line with what Bellan et al., (2015) suggested in their study that over trails participants become more susceptible towards the illusion. For the control group, one could argue that visual capture during the adaptation task could be driving their judgements; however, this is only apparent for HfA group when the distance is increased above 100 units.

Results gathered from experiment five and six indicate that individuals with high autism traits and those with a clinical diagnosis of HfA make fewer errors in estimating the location of their hand, however, the results do not indicate that there is an inclination towards proprioception, which has been suggested in other studies (Palmer et al., 2013; Paton et al., 2012). Previous research that has used the rubber hand paradigm and full body illusions, such as the mannequin illusion, have presented us with mixed results, however, most studies highlight proprioception as a core characteristic that the autistic population seems to excel at. However, even though the results of the current investigation do suggest that individuals with high autism traits and those with HfA are better at localization tasks when no visual input is provided and proprioceptive information is not congruent, it cannot be confirmed that these results indicate an over- reliance on proprioception as that would show accurate or above accurate performance. However, it could be argued that individuals with HfA are more aware of their internal sensory processes as compared to typically developing controls. Having a higher reliance or internal awareness could explain why they are making lesser displacement errors. Comparing the results of these two investigations to those that have been done in the past, one could argue that task differences and task difficulty could be a reason why both groups made more estimation errors when the distance between the hands was increased. This could be backed up by suggesting that if the task itself was easy, there would have been no estimation errors, especially during the baseline condition. Therefore, participants from both groups were overestimating the location.

In terms of the HfA group, their performance was overall superior than the typically developing adults, as they made estimates closer to the location on the hand in real-time. The adaptation procedure during the beginning of the task involves an illusion where participants are tricked into believing that their hand has shifted from where it last was (for a more detailed review of the adaptation task please see: Newport & Gilpin, 2011). The visual input indicates that the participants hand is in the same place; however, the proprioceptive information is giving a different feedback. For arguments sake, if there is over- reliance over proprioception in autism, we would expect close to accurate judgments, regardless of condition, because in the trade-off between the two independent sensory inputs, people with HfA would always choose the proprioceptive input. However, even though the results do not support this idea, the data shows a trend of consistent selection of "proprioceptive feedback" over any other sensory input.

An alternate explanation to explain these results could be explained in reference to the "extended temporal binding window" hypothesis of autism (Foss-Feig et al., 2010). This theory suggests that the temporal timing during which two sensory inputs are combined is larger for those with ASD compared to the typically developing population. This has been tested using the flash beep illusion and the results of the investigation revealed that children with autism do indeed report the flash- beep illusion over an extended range of stimulus onset asynchronies. Therefore, the temporal binding window for autistic children is wider compared to those of typical development (Foss-Feig et al., 2010). This indicates that if the binding window is extended in autism, they would report the subjective effects of the illusion. Recently, Greenfield and Colleagues (2015) tested this theory in children with autism and found support for the temporal binding hypothesis (Greenfield et al., 2015). Even though the current investigation did not explicitly test this theory, it can be argued that over trails individuals with HfA were susceptible to the illusion which is why during the first trial (7.5 cm) their estimates were based on proprioceptive information, however, over trails, these estimates shifted from the "proprioceptive zone" towards the "visual zone". Hypothetically, one could argue that the temporal binding window that deals with internal processes could also occur at a physical level i.e. in terms of the time taken for an individual to experience the illusion, and the longer the individual is exposed to the illusion, the more likely they are to be susceptible towards it. (Figure 8.2 illustrates the summary of the results of experiment six and seven).

Conditions	**Groups**	**Displacement 1 (100 units)**
Congruent Seen	High AQ	+
	Low AQ	+
	HFA	+
	TD	++
Congruent unseen	High AQ	++
	Low AQ	++

	HFA	+	**Displacement 2 (120 units)**	**Displacement 3 (150 units)**
	TD	++		
Incongruent Unseen	High AQ	-		
	Low AQ	--		
	HFA	+	-	--
	TD	--	--	---

Table.8.3. Table shows the summary of the results obtained from chapter 6 and 7. This investigated visuo proprioceptive illusion susceptibility in individuals of TD with high and low AQ traits and those with HFA. + = represents estimations made on the right-hand side of the midline (where the real finger is). ++ indicates drift towards the proprioceptive zone**.** – represents estimations made on the left side of the midline. This represents a greater reliance on visual information. Similarly, **--** indicates greater reliance on visual input. Please note that these are made on assumptions gathered from the data collected from experiment 5 and 6.

8.3. Theories of Autism and Perceptual Performance

Recent research investigating visuo- tactile integration in autism has indicated a fundamental over- reliance on proprioception, while disregarding other sensory inputs, during tasks that measure visual, tactile and proprioceptive integration in autism and similar tendencies have been suggested in the typically developing population with high autism traits but to a lesser extent (Cascio et al., 2008; Cascio et al., 2012; Palmer et al., 2013; Paton et al., 2012). As the current investigation involves the TD population, we can suggest that these individuals integrate sensory information in a statistically optimal manner, where sensory inputs received from the sources will be integrated in the best possible manner to execute an accurate response. Therefore, an over- reliance on a single sensory source, such as "proprioception" would lead to atypical perception. Keeping in line with this theory, one would expect superior proprioceptive performance during tasks which measure such activities. For example, in a sensory discrimination task, when an autistic individual is asked to differentiate between different sensory sources, this individual would be better at identifying the proprioceptive inputs or would almost always show a bias for proprioception compared to other sensory sources.

The results gathered in this thesis indicate superior proprioceptive performance in individuals with HfA and those with high autism traits. However, one cannot definitely argue that there is indeed an over- reliance. If there was indeed an over reliance, the results of the finger stretching estimates would show accurate judgements in identifying location of their right fingertip across all the conditions, i.e. accurate localization of the fingertip regardless of the condition. However, the results found that the HfA group and high AQ groups were better than the control and the low AQ group in localization of the fingertip, but they were not accurate across all conditions. Furthermore, during the disappearing hand illusion, participants with autism and those with high autism traits, made more errors as the distance between the hands increased. Also, as the distance increased both groups showed a trend to move from the proprioceptive plain towards the visual plain displaying an effect of the illusion. Therefore, the data gathered in this thesis provides support for an over- reliance on proprioception in autism, but argues that instead of fundamental over- reliance, there is a preference for proprioception as opposed to visual and tactile information in the autistic population. It is also important to note that increase in errors during the task can also be attributed to task difficulty, whereby, as the distance between the hands increased, participants made more localization errors such that seeing the hand move further from the start point would generate an expectance to estimate the hand further to over compensate for the larger difference between the hands. For the typically developing individuals, it can be argued that the stored cognitive visual information during the hand movement is compensating for the unavailability of visual input during the localization task. But, for the HfA group, this mechanism of compensating for the missing information starts with a delay, therefore, their estimates shift from proprioceptive to visual field as the distance between the hands increases. However, to further understand this relationship, I will now discuss the traditional theories of autism.

Visual phenomena at times can provide us with a distorted and illusory view of the physical environment around us, which is commonly referred to as visual illusions. Even though it is a distortion of what the reality is, these processes are considered important and tell us how our visual system adapts towards the environment. Happé (1996) was one of the first to report perceptual abnormalities of visual illusory figures in autism (i.e. Ponzo illusion, Kanizsa and Titchener illusions, the Müller-lyer illusion and the Poggendorf illusions) by comparing the performance of children with autism and those with other learning disabilities and typical developing children (using verbal judgements), she proposed that the autistic group was less susceptible to the illusion, hence, she linked WCC at low- level perceptual atypicalities with ASD. Later on, Ropar and Mitchell (1999) demonstrated that children with autism are in fact equally susceptible to the aforementioned illusions (using both a computer task and a verbal response task). Furthermore, in a later study, Ropar and Mitchell (2001) replicated their earlier findings and demonstrated that children with autism and those with Asperger's syndrome performed better than the controls on the WCC- related visuospatial tasks (embedded figures task, block design task and the Rey complex figures task) and they proposed that alternate accounts should be put forward to explain the perceptual abnormalities in autism.

The Weak Central Coherence theory (WCC) (Happé, 2005) and the Enhanced perceptual processing theory (EPF) (Mottron et al., 2001), are the two most prominent cognitive theories of autism and perceptual processing today. Based on Happé's (1996) findings, the WCC theory argues a deficit in global processing and a detailed focused cognitive style (Happé, 2005), whereas, the EPF argues that there is enhanced lower-level processing without making any claims regarding a global deficit in autism. In the grand scheme of things, both these theories argue that atypical perceptual systems in autism are due to perceptual problems where autistic individuals are more detail oriented and focus more on the lower- level sensory processes (Frith & Happé, 1994; Happé et al., 2006a; Sheppard et al., 2009) and the results of these investigations do in fact support these theories. Experiment's one and two explored visual processing in individuals with high autism traits and those with HfA using a visual illusion that induces somatosensory sensations by manipulating the visual information in the absence of any tactile input (McKenzie & Newport, 2015). The results of the study indicated reduced sensitivity to visual distortion (bottom- up sensory information) in both the High AQ group and HfA group. Therefore, the weak central coherence theory would predict that the global context of the situation, in this case the pixelated effect on the hand, should not bias lower- level sensory processes, therefore, the performance of those with HfA and high autism traits should be consistent with the control conditions. On the other hand, the enhanced perceptual functioning theory would indicate superior lower- level sensory performance for which we would expect consistent and enhanced subjective reports across all conditions or the tingling felt on the hand as a consequence of superior local processing during the experimental condition which would be enhanced compared to the typically developing group or low autism trait participants. However, none of these outcomes can be explained under the EPF theory, which perhaps lends more weight towards the weak central coherence theory. In the context of the crawling skin illusion, the results demonstrate that individuals with high autism traits and those with HfA fail to comprehend the global context of the illusion, therefore, not reporting visually induced sensations or individuals with autism and those with high AQ traits do not comprehend the global aspect of the illusion but they process sensory information separately (local processing).

As the data gathered in the current thesis not only investigates susceptibility towards illusions in autism, it also highlights how sensory integration takes places in the typically developing population, therefore, it is important to understand how these mechanisms are in the typically developing populations. Tsakiris (2016) suggested that perception is based upon the interaction between top- down predications about the world and bottom- up sensory information in the form of predictive errors. For the comparison group and those with low autism traits, illusion susceptibility and finger estimation tasks are heavily influenced by the co-current sensory information regarding the fingertip during the finger stretching illusion and the disappearing hand trick, indicating that bottom- up information is over riding the existing knowledge regarding the finger, therefore, they are falling for the illusion indicating a bidirectional loop that is constantly being updated. However, this is not the case for those high in autism traits and adults with HfA. There seems to be a disconnect between the two sensory channels, where the bottom- up information is not updating the top-down knowledge, therefore, these individuals do not tend to fall for the illusion. Such a disconnect would prevent lower-level sensory input from updating higher order representations as well as preventing those higher order representations from modulating the experience of sensory input. In line with these explanations, another possible argument could be that the updating loop (sensory information interacting with top- down knowledge) is rigid or limited in autism. Such a deficit would explain why those individuals with autism fail to adapt to new social situations, where sensory information needs to be integrated and interpreted as meaningful with existing cognitive states and why those existing states fail to be modified by incoming sensory signals (Ahissar & Assa, 2016; Rief et al., 2015).

Research has suggested that proprioception is an internal sense, whereby, it measures the actions to be taken internally with the help of external information achieved through the external senses. Proprioception on its own is an area that is less studied in the autistic population. Blanche et al., (2012) investigated proprioceptive processing difficulties among children with autism and developmental disabilities and a comparison group. They used the comprehensive observations of proprioception (COP) questionnaire to identify and describe the proprioceptive difficulties amongst the various disabilities. The COP is a clinically based method that helps clinicians to identify adequate muscular movement, such as muscle tone or joint alignment, and compares that to a preset benchmark that identifies deviations from typical parameters, such as decreased muscle tone and joint alignment. The results of this investigation indicated that children with ASD (n = 32) present with proprioceptive difficulties that are qualitatively different from those children with other developmental disabilities (n = 26) and their typically developing counterparts (n = 28) (Blanche et al., 2012). This indicates that proprioceptive abilities of children autism are different from those with other disabilities. Even though the validity and reliability of COP has yet to reach research validation, this provides us with a means of measuring proprioceptive disabilities in individuals with autism. This along with proprioceptive tasks could increase our knowledge regarding the qualitative and quantitative differences. This further, ties in with how sensory profiling and studying them individually in relation to the domain specific deficits identified using a SPQ.

In conclusion, the data gathered in this thesis cannot be fully explained by a single theory of autism and perceptual processes. As the overall aim of the current thesis was to measure illusion susceptibility across the autistic population, the aforementioned theories were not directly tested. However, in the grand scheme of things, the results of the current thesis provide evidence for the EPF theory as the results gathered in the current thesis show that individuals with HfA and those with high autism traits are over- relying on lower- level sensory information but this sensory information is not affecting their top- down knowledge regarding their own body parts. Furthermore, sensory integration is atypical in autism such that individuals with autism and those with high autism traits are contextually driven but they tend to show superior proprioceptive abilities, indicating a higher reliance on internal sensory sources as opposed to the traditional five senses.

8.4. Limitations and Future Direction

The work presented in this thesis provides us with information regarding how visual, tactile and proprioceptive information is integrated in those individuals with autistic traits and adults with a diagnosis of high- functioning autism. Past research has explored how visual and auditory information is manipulated in autism; however, far fewer studies have studied visual, tactile and proprioceptive integration in autism, using illusions that manipulate one's own limbs. The need to increase our knowledge in these domains has increased as individuals with autism are reporting more sensory issues related to these domains.

One of the main limitations of this work is that none of these studies measured sensory severities of participants who took part in these experiments. It is reported that between 45 to 95 % of children and adults with autism presents a sensory feature that affects their everyday living and social life (Perez Repetto et al., 2017). Sensory processing as a process is the way through which the central and the peripheral nervous systems receive, interpret and respond to sensory information. On one hand, the exact nature of this sensory input can vary tremendously (for example, smell, touch, proprioception) and the organization of this information contributes to the development of muscle tone, motor skills, self- awareness, interactions with others, and everyday functioning (Ayres et al., 2000). However, on the other side, there is the quality and reliability of the sensory information received, which also plays an equally important role in determining the effectiveness of this process. Considering that autism as a condition represent a very unique etiology, the severity of the impact of the disorder defers greatly between individuals. Furthermore, sensory profiles of individuals with autism are very rarely identical because an individual with a visual deficit might also have a proprioceptive deficit, or none of these and just an auditory deficit. The magnitude at which these sensory deficits occur are usually characterized by “hypo” or “hyper- responsiveness”. Therefore, controlling for sensory severities using a sensory profile questionnaire is extremely important for sensory research in autism. Especially, using sensory severity scales or sensory profiles for each sensory domain being studied can provide us with great knowledge regarding an individual’s sensory profile and their performance on the task. These results can be compared and further altercations can be made to tasks to further enhance our knowledge. Not only will it help gain more knowledge regarding the myriad of sensory atypicalities in autism but it will provide us to compare task performance and sensory abilities.

The data gathered from this thesis cannot be generalized across the entire autistic population as it cannot be directly said that superior proprioceptive performance is constant across everyone with an ASC diagnosis. As sensory severities vary across sensory domains in both quality and quantity, it is not clear whether a particular group with a unique set of sensory symptoms performs this way or it is common across all participants. For instance, the results of study indicate superior proprioceptive performance in those with high AQ scores and those with HfA, however, what it could not measure was whether the studied autistic group had a unique sub set of sensory skills which were modulating the outcome. Sensory profiling in autism is of extreme importance as this can help practitioners with establishing therapies designed individually for a person with a unique sensory profile. Therefore, one possible direction the current investigation could head in is by employing sensory profiling methods as an added measure when testing individuals with autism. This can help us in understanding if individuals with autism who show superior performance in proprioception have a more tactile superior profile, while there is hyper- responsiveness in the other sensory domains. Gathering this sensory profiling data can help us further understand what the most prominent sensory profiles of autism. It is also important to state that after extensive search online, there are no sensory severity standardized tests available in the scientific community that are not self- report measures.

The findings of the current study should be treated with caution due to the small sample size, even though, the post- hoc power analysis showed that the sample size is enough, however, the small sample size limits statistical power and reliability of the results. Small sizes are especially problematic in autism research due to the great variability in symptoms and presentation between affected individuals (Kleberg, 2014). More so, although restricting the sample to high- functioning adults with autism can limit the variability with the sample and increase statistical power, it creates a non-representative sample and can have significant implications on the ability to draw conclusion on the entire ASD population. Another possible limitation of the current study could be the way the subjective statements were designed. Even though they have been used before in both typically developing groups and children and adults with autism, it still needs to be considered that individuals with autism are very context dependent and take things literally. Therefore, using the right language to measure the exact process should be given extra attention.

Another possible limitation is the screening of typically developing individuals using the Autism Spectrum Quotient (Baron-Cohen et al, 2001a). The AQ is a very popular, self-report measure which is designed around the core deficits of autism: Communication, social skills, repetitive behaviors, attention to detail and imagination. The reliability and validity of the AQ has been proven over and over again (Baron-Cohen et al., 2001a; Gregory & Plaisted-Grant, 2016; Lundqvist & Lindner, 2017; Ruzich et al., 2015a), however, most studies have used only a single measure to measure these traits. Recent reviews of the AQ have suggested that the cut-off score for those with significant traits of autism is a score of 32 and above. It is suggested that after this cut-off score one can see quantitative differences in AQ traits that are clinically similar to those with an ASC diagnosis. This was controlled for in the current study as all high AQ scorers who took part in this study had a score of 32 and above on the AQ. However, using the AQ as the only screening measure could confound the results. Therefore, further studies could use extra measures, such as the Empathizing quotient and the systemizing quotients, to confirm the traits measure. Not only this, but individuals with AQ traits can also be screened using the sensory profile questionnaires, to check for any relationships between high AQ traits and sensory profiles of those with autism traits and those with a diagnosis of autism. This could help generate data to further confirm that sensory symptoms, just like imagination and social and non-social traits, which are present in the typically developing populations, are consistently spread across the spectrum, where symptoms are more severe in those with a clinical diagnosis of autism.

Recruitment of typically developing adults is easier compared to those with a clinical diagnosis of autism, however, screening individuals with high autism traits (a score of 32 and above) is rather time- consuming. Establishing a study with higher numbers of individuals with a score of 32 and above can provide us with more insight regarding the quantitative and qualitative differences in how individuals with high AQ scores perform against those with an autistic disorder over sensory illusions. The score of 32 and above has been shown to be the score that has been suggested as the cut-off score where you see quantitative behavioral similarities between individuals of typical development and those with a diagnosis of autism and this has been demonstrated in a systematic review of the scores gathered from a sample of 6,900 typically developing individuals (Ruzich et al., 2015a). Even though, the results gathered from the current thesis are promising, another possible direction to further investigate these mechanisms would be to measure the susceptibility of individuals of typical development with autism traits across the whole spectrum. Most research has used high versus low to measure susceptibility differences; therefore, differences are varying amongst each of these studies.

However, looking into the whole spectrum and how susceptible these individuals with varying traits could provide us with more promising insights.

Another possible direction to further expand on these findings is to conduct these illusions on individuals with a clinical diagnosis of autism with a diagnosis of low functioning, who present a more severe symptom profile. They tend to present more complicated and stringent sensory profiles resulting in difficulty for caretakers to manage their behaviors. Symptoms in individuals who are low functioning tend to get diagnosed earlier in life. The MIRAGE system (Newport et al., 2015; Newport & Gilpin, 2011) can be used to further enhance our knowledge regarding proprioceptive functioning earlier in life. This can be done by conducting studies that measure visual, tactile and proprioceptive functioning in typically developing children and adults to understand how and when proprioception as a sense is the strongest and how with age reliance on this “sixth sense’ is increased or decreased. Understanding and establishing a developmental pattern of such processes can help us establish developmental trajectories in autism by measuring the same processes from early years of life to the ages of 18 when it the sensory systems are thought to be fully developed.

Furthermore, the findings from experiment five and six provide us with data that could be further explored on. In experiment five, individuals with high and low AQ traits were subjected to a visuo- proprioceptive illusion which required them to estimate their right index finger location when both vision and proprioceptive information was manipulated. In study six, individuals with HfA were required to do the same task, however, this time the distance between the hands was increased. Previous studies have indicated that ownership of the hand is positively correlated with the distance between the seen and unseen hands, such that studies have shown that ownership of the hand is restricted to near distances only (Preston, 2013; Daprati et al., 2019; Lloyd., 2007; Peck et al., 2013; Philip, 2010; Parket et al., 2017). Therefore, the experiments in the current thesis indicate a pattern which suggests that individuals with high autism traits and those with high- functioning autism seem to be susceptible to certain illusory paradigms, however, they require exposure towards the paradigm for a long duration, i.e. several trails are need. In line with this idea, future experiments could establish experimental paradigms could use virtual reality to manipulate the timings and trails in order to test whether over trails and after a certain period of time individuals with autism are susceptible towards multisensory illusions. Furthermore, this will provide evidence for the enhanced temporal binding window hypothesis for autism (Zhou et al., 2019; Yaguchi et al., 2018; Chan et al., (2016).

8.5. Implications of the Current Research

There seems to be an abundance of research looking at various underlying reasons why the sensory profiles of autistic minds are different from the typically developing brain. While, most of these studies, have contributed tremendously towards the knowledge that we have, there seems to be uncertainty as to what contributes to the "traids of impairments in autism". This is because; research indicates that sensory systems are an extremely important ability that forms the basis of social and non- social deficits reported in autism. The success of sensory integration therapies has led more people to seek therapy (Thurm, 2012). Even more, knowing more about this condition could be a very important factor in establishing evidence- based sensory integration therapies for children with autism.

Studying sensory integration in individuals with autism can help us gain more knowledge and insight into how this particular group of people process sensory information. Sensory integration therapies have gained a lot of popularity in the recent years, however, most of these therapies focus towards improving visual and auditory integrations, however, little focus is given to tactile integration even though it is well- understood that tactile integration plays a key role in early development and the development of social and non- social attributes (Güçlü et al., 2007; Marco et al., 2011). Furthermore, parental reports detailing sensory profiles of their children often highlight issues with tactile processing, i.e. understanding textures and development of movement, as one of the biggest and most challenging aspects of sensory problems in individuals with autism. These issues can make ordinary situations feel overwhelming, so much so that they can interfere with the individuals daily functioning and even result in isolation from the world (Schaaf et al., 2014). Therefore, it is extremely important to understand how visual- tactile processing takes places in autism and understand the role of proprioception to create interventions which can help individuals with autism and their sensory- motor difficulties.

Understanding sensory integration does not only involve studying the sensory information and how it's being processed, however, future research should also focus on understanding how this information is collected and integrated with higher- level processes, such as one's existing cognitive knowledge. It is often reported that individuals with autism show a preference for lower- level sensory information but they do not integrate this with their existing knowledge, hence, resulting in atypical reactions (Baranek et al., 2006; Hames et al., 2016; Kern et al., 2006, 2007; Matsushima & Kato, 2013). Therefore, understanding at what stage of integration these processes do not update each other is extremely important. For example, the findings of my study indicate that individuals with HfA to tend to move from using a single sensory modality towards another, however, they take a longer duration in doing so compared to typically developing groups. Therefore, this should be noted and kept in mind when coming up with new interventions. Furthermore, understanding and developing developmental trajectories using sensory profiles of individuals with autism can further help us understand how sensory information is developed over time and at which point individuals with autism start shifting from the norm. This is important as it has already been shown that typically developing children unlike adults are more prone to shift between the usage of visual and proprioceptive information given the task at hand, however, adults do not show this variation and after a certain age are completely reliant on both senses (Bremner et al., 2013).

The results of this investigation have indicated that individuals with HfA show superior proprioceptive abilities compared to those of typical development and this finding is in line with studies conducted previously, where it has been suggested that there is over- reliance on proprioception in ASD (Paton et al., 2012; Palmer et al., 2013), however, in this thesis I suggest that individuals with HfA are more attuned to information emitting from within or a source closer to the body rather than relying on information that is obtained through external sensory sources. For example, Experiment six measured visual and proprioceptive abilities in individuals with HfA. The experimental condition task required participants to locate the index finger without visual input and incongruent proprioceptive information. The argument here is that, vision modulates proprioception. Therefore, during the task participants rely on the visual information gathered during the adaptation task (location where the hand was seen last). However, this does not happen for those with HfA, as there seems to be a stronger preference for proprioceptive input rather than the information present during the visual capture. This has been suggested before but no study has investigated this in relation to proprioception as a concept, identical to how the autistic brain is an introspective brain.

The findings from this study highlight various practical implications that can contribute towards the wider knowledge regarding autism. It is well understood that individuals with autism have a detail- oriented cognitive style of processing. They tend to pay more attention to details compared to the TD population. Including an imagination deficit, it is important to design studies that take this into context. Such as, any study that involves in-cooperating an external object into one’s body schema, an individual with an imagination deficit will be less attuned to overcome the cognitive differences. As well as the RHI or the robotic arm paradigm is, there could be the possibility that the cognitive aspect of external objects i.e. the ability to imagine the hand as your own, while disregarding the contextual differences between the real and the fake hand, could hinder those with autism, which could reflect the variability of the results gathered from the past research. It is an important aspect to consider as this research is based on individuals with an autism spectrum condition which has been known for its imaginative deficit being a core diagnostic criterion and there is a plethora of research measuring this deficit in relation to social and cognitive development (Calder et al., 2015; Donohue et al., 2012; Frith & Happé, 1994a; Elwin et al., 2012; Low et al., 2009; Whyatt & Craig, 2013), to my knowledge very little has been known how it would reflect in terms of illusion susceptibility which requires a cognitive skill that is not developed in autism. It might seem like a small difference in the grand scheme of the research, but this could impact the outcome of research greatly. Therefore, in the light of the research presented in this thesis, I suggest that the MIRAGE provides a substitute to further explore sensory integration in autism. Previous research that had used multimodal illusions to understand MSI in autism have overlooked this important aspect, as it can heavily affect the style of judgements of the participants.

8.6 Conclusions

In conclusion, the core findings of the current thesis are as follows, typically developing individuals with high and low autism traits and those with high- functioning autism show various similarities in susceptibility towards sensory illusion. Of particular interest are the close behavioral similarities in the context of illusion susceptibility between high AQ scorers and adults with HfA. The MIRAGE system (Newport et al., 2010) is a great tool for investigating body ownership and embodiment in individuals with high- functioning autism as this is evidenced by the high ownership scores obtained from participants throughout the course of this thesis. The results also indicate that typically developing individuals with high autism traits and those with HfA do not show a fundamental bias towards processing information from a single sensory source, i.e. proprioception, as previously suggested (Palmer et al., 2013; Paton et al., 2012; Piven et al., 1997). However, the results of this thesis show an overall preference for or superior proprioceptive performance in the high AQ and autistic groups when there is an interplay between multiple sensory sources (such as visual, tactile and proprioception). It is beyond the scope of the current thesis to provide exact mechanisms underlying atypical sensory integration in autism or superior proprioceptive performance. However, the results gathered during this investigation and their interpretation have very important implications for future research, particularly in establishing evidenced- based interventions to lessen the atypical sensory symptoms often reported in autism. Proprioception can be argued to be the sense that tells the body where it is relation to the space. This internal sense plays a major role in self-regulatory behaviors, coordination, and body awareness and also impacts the ability to attend to and process speech and visual processes. Further research should focus on identifying core deficits in autism using a sensory profile checklist that examines proprioceptive performance. Furthermore, with the use of MIRAGE mediated reality system, future studies should focus on establishing tasks that measure proprioceptive performance in individuals with high-functioning autism and also those with a core diagnosis of autism who are low functioning.

References

Adolphs, R. (2003). Cognitive neuroscience: Cognitive neuroscience of human social behaviour. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn1056

Ahissar, E., & Assa, E. (2016). Perception as a closed-loop convergence process. *ELife, 5*, 235–273. https://doi.org/10.7554/elife.12830

American Psychiatric Association. (2013a). American Psychiatric Association. Diagnostic and statistical manual of mental disorders (5th ed.). In *American Journal of Psychiatry*. https://doi.org/10.1176/appi.books.9780890425596.744053

American Psychiatric Association. (2013b). Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5). *Diagnostic and Statistical Manual of Mental Disorders 4th Edition TR.*, 280. https://doi.org/10.1176/appi.books.9780890425596.744053

Amoruso, L., Narzisi, A., Pinzino, M., Finisguerra, A., Billeci, L., Calderoni, S., Fabbro, F., Muratori, F., Volzone, A., & Urgesi, C. (2019). Contextual priors do not modulate action prediction in children with autism. *Proceedings of the Royal Society B: Biological Sciences*, *286*(1908), 20191319. https://doi.org/10.1098/rspb.2019.1319

Apker, G. A., Karimi, C. P., & Buneo, C. A. (2011). Contributions of vision and proprioception to arm movement planning in the vertical plane. *Neuroscience Letters*, *503*(3), 186–190. https://doi.org/10.1016/j.neulet.2011.08.032

Armel, K. C., & Ramachandran, V. S. (2003). Projecting sensations to external objects: evidence from skin conductance response. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *270*(1523), 1499–1506. https://doi.org/10.1098/rspb.2003.2364

Ayres, T., Wood, C., Schmidt, R., Young, D., & Murray, J. (2000). Affordance Perception and Safety Intervention. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *44*(32), 6–51. https://doi.org/10.1177/154193120004403214

Bahrick, L. E., Todd, J. T., & Soska, K. C. (2018). The Multisensory Attention Assessment Protocol (MAAP): Characterizing individual differences in multisensory attention skills in infants and children and relations with language and cognition. *Developmental Psychology*, *54*(12), 2207–2225. https://doi.org/10.1037/dev0000594

Baio, J., Wiggins, L., Christensen, D. L., Maenner, M. J., Daniels, J., Warren, Z., Kurzius-Spencer, M., Zahorodny, W., Robinson, C., Rosenberg, White, T., Durkin, M. S., Imm, P., Nikolaou, L., Yeargin-Allsopp, M., Lee, L.-C., Harrington, R., Lopez, M., Fitzgerald, R. T., Dowling, N. F. (2018). Prevalence of Autism Spectrum Disorder Among Children Aged 8 Years — Autism and Developmental Disabilities Monitoring Network, 11 Sites, United States, 2014. *MMWR. Surveillance Summaries*, *67*(6), 1–23. https://doi.org/10.15585/mmwr.ss6706a1

Balasco, L., Provenzano, G., & Bozzi, Y. (2020). Sensory Abnormalities in Autism Spectrum Disorders: A Focus on the Tactile Domain, From Genetic Mouse Models to the Clinic. In *Frontiers in Psychiatry*. https://doi.org/10.3389/fpsyt.2019.01016

Bao, V. A., Doobay, V., Mottron, L., Collignon, O., & Bertone, A. (2017). Multisensory Integration of Low-level Information in Autism Spectrum Disorder: Measuring Susceptibility to the Flash-Beep Illusion. *Journal of Autism and Developmental Disorders*, *47*(8), 2535–2543. https://doi.org/10.1007/s10803-017-3172-7

Baranek, G. T. (2002). Efficacy of Sensory and Motor Interventions for Children with Autism. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1023/A:1020541906063

Baranek, G. T., David, F. J., Poe, M. D., Stone, W. L., & Watson, L. R. (2006). Sensory Experiences Questionnaire: Discriminating sensory features in young children with autism, developmental delays, and typical development. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *47*(6), 591–601. https://doi.org/10.1111/j.1469-7610.2005.01546.x

Baron-Cohen, S. (2004). The cognitive neuroscience of autism. *Journal of Neurology, Neurosurgery and Psychiatry*. https://doi.org/10.1093/nq/s3-IX.225.330-a

Baron-cohen, S., Leslie, A. M., & Frith, U. T. a. (1985). The autistic child have a "theory of mind"?. *Cognitive Development*, *21*, 37–46. https://doi.org/10.1016/0010-0277(85)90022-8

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001a). The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-Functioning Autism, Males and Females, Scientists and Mathematicians. *Journal of Autism and Developmental Disorders*, *31*(1), 5–17. https://doi.org/10.1023/A:1005653411471

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001b). The Autism Spectrum Quotient : Evidence from Asperger syndrome/high functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders*, *31*(1), 5–17. https://doi.org/10.1023/A:1005653411471

Baron-Cohen, Simon. (1989). The autistic child's theory of mind: a case of specific developmental delay. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *30*(2), 285–297. https://doi.org/10.1111/j.1469-7610.1989.tb00241.x

Bayliss, A. P., & Kritikos, A. (2011). Brief report: Perceptual load and the autism spectrum in typically developed individuals. *Journal of Autism and Developmental Disorders*, *41*(11), 1573–1578. https://doi.org/10.1007/s10803-010-1159-8

Bayliss, A. P., Bartlett, J., Naughtin, C. K., & Kritikos, A. (2011). A direct link between gaze perception and social attention. *Journal of Experimental Psychology. Human Perception and Performance*, *37*(3), 634–644. https://doi.org/10.1037/a0020559

Bebko, J. M., Weiss, J. A., Demark, J. L., & Gomez, P. (2006). Discrimination of temporal synchrony in intermodal events by children with autism and children with developmental disabilities without autism. *Journal of Child Psychology and Psychiatry* *and Allied Disciplines*, *47*(1), 88–98. https://doi.org/10.1111/j.1469-7610.2005.01443.x

Behrmann, M., Avidan, G., Leonard, G. L., Kimchi, R., Luna, B., Humphreys, K., & Minshew, N. (2006). Configural processing in autism and its relationship to face processing. *Neuropsychologia*, *44*(1), 110–129. https://doi.org/10.1016/j.neuropsychologia.2005.04.002

Bellan, V., Gilpin, H. R., Stanton, T. R., Newport, R., Gallace, A., & Moseley, G. L. (2015). Untangling visual and proprioceptive contributions to hand localisation over time. *Experimental Brain Research*, *233*(6), 1689–1701. https://doi.org/10.1007/s00221-015-4242-8

Belmonte, M. K. (2004). Autism and Abnormal Development of Brain Connectivity. *Journal of Neuroscience*, *24*(42), 9228–9231. https://doi.org/10.1523/jneurosci.3340-04.2004

Berberovic, N., & Mattingley, J. B. (2003). Effects of prismatic adaptation on judgements of spatial extent in peripersonal and extrapersonal space. *Neuropsychologia*, *41*(4), 493–503. https://doi.org/10.1016/S0028-3932(02)00090-8

Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2005). Enhanced and diminished visuo-spatial information processing in autism depends on stimulus complexity. *Brain*, *128*(10), 2430–2441. https://doi.org/10.1093/brain/awh561

Biklen, D., Attfield, R., Bissonnette, L., & Blackman, L. (2005). *Autism and the Myth of the Person Alone (Qualitative Studies in Psychology, 3)* (Illustrated ed.). NYU Press.

Bird, G., Leighton, J., Press, C., & Heyes, C. (2007). Intact automatic imitation of human and robot actions in autism spectrum disorders. *Proceedings of the Royal Society B: Biological Sciences*, *274*(1628), 3027–3031. https://doi.org/10.1098/rspb.2007.1019

Blakemore, S. J., Tavassoli, T., Calò, S., Thomas, R. M., Catmur, C., Frith, U., & Haggard, P. (2006). Tactile sensitivity in Asperger syndrome. *Brain and Cognition*, *61*(1), 5–13. https://doi.org/10.1016/j.bandc.2005.12.013

Blanche, E. I., Reinoso, G., Chang, M. C., & Bodison, S. (2012). Proprioceptive processing difficulties among children with autism spectrum disorders and developmental disabilities. *American Journal of Occupational Therapy*, *66*(5), 621–624.

https://doi.org/10.5014/ajot.2012.004234

Bölte, S., Holtmann, M., Poustka, F., Scheurich, A., & Schmidt, L. (2006). Gestalt Perception and Local-Global Processing in High-Functioning Autism. *Journal of Autism and Developmental Disorders*, *37*(8), 1493–1504. https://doi.org/10.1007/s10803-006-0231-x

Bosse, D., Fick, A., & Poljansek, T. (2015). Husserl, Cassirer, Schlick: “Scientific Philosophy” Between Phenomenology, Neo-Kantianism and Logical Empiricism. *Journal for General Philosophy of Science*, *46*(1), 225–229. https://doi.org/10.1007/s10838-014-9278-0

Boston, D. (1977). Hearing Lips and Seeing Voices. *British Journal of Audiology*, *11*(3), 86–87. https://doi.org/10.3109/03005367709078839

Botvinick, M. (2004). Probing the Neural Basis of Body Ownership. *Science*, *305*(5685), 782–783. https://doi.org/10.1126/science.1101836

Botvinick, M., & Cohen, J. (1998). Rubber hands “feel” touch that eyes see. *Nature*, *391*(6669), 756. https://doi.org/10.1038/35784

Boyd, B. A., Baranek, G. T., Sideris, J., Poe, M. D., Watson, L. R., Patten, E., & Miller, H. (2010). Sensory features and repetitive behaviors in children with autism and developmental delays. *Autism Research*. https://doi.org/10.1002/aur.124

Boyd, B. A., McBee, M., Holtzclaw, T., Baranek, G. T., & Bodfish, J. W. (2009). Relationships among repetitive behaviors, sensory features, and executive functions in high functioning autism. *Research in Autism Spectrum Disorders*. https://doi.org/10.1016/j.rasd.2009.05.003

Bremner, A. J., Hill, E. L., Pratt, M., Rigato, S., & Spence, C. (2013). Bodily Illusions in Young Children: Developmental Change in Visual and Proprioceptive Contributions to Perceived Hand Position. *PLoS ONE*, *8*(1). https://doi.org/10.1371/journal.pone.0051887

Brett-Green, B. A., Miller, L. J., Gavin, W. J., & Davies, P. L. (2008). Multisensory integration in children: A preliminary ERP study. *Brain Research*, *1242*, 283–290.

https://doi.org/10.1016/j.brainres.2008.03.090

Brisson, J., Warreyn, P., Serres, J., Foussier, S., & Adrien-Louis, J. (2012). Motor anticipation failure in infants with autism: a retrospective analysis of feeding situations. *Autism*, *16*(4), 420–429. https://doi.org/10.1177/1362361311423385

Brisson, J., Warreyn, P., Serres, J., Foussier, S., & Adrien-Louis, J. (2012). Motor anticipation failure in infants with autism: A retrospective analysis of feeding situations. *Autism*. https://doi.org/10.1177/1362361311423385

Brooks, J., & Medina, J. (2017). Perceived location of touch. *Scholarpedia*, *12*(4), 42285. https://doi.org/10.4249/scholarpedia.42285

Buckingham, G., & Goodale, M. A. (2010). Lifting without seeing: The role of vision in perceiving and acting upon the size weight Illusion. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0009709

Calder, A. J., Ewbank, M., Passamonti, L., Fernandes Jr, O., Hamann, S., Canli, T., Kanai, R., Rees, G., Oliveira, L. L., Mocaiber, I. F., David, I. P. A., Erthal, F. S., Volchan, E., Pereira, M. G., de Oliveira, L. L., Joffily, M., Pessoa, L., Pichon, S., De Gelder, B., de Araujo, D. B. (2015). Emotion and attention interaction: a trade-off between stimuli relevance, motivation and individual differences. *Frontiers in Human Neuroscience*. https://doi.org/10.1196/annals.1387.029

Calvert, G. A., & Thesen, T. (2004). Multisensory integration: Methodological approaches and emerging principles in the human brain. *Journal of Physiology Paris*, *98*(1-3 SPEC. ISS.), 191–205. https://doi.org/10.1016/j.jphysparis.2004.03.018

Calvert, G. A., Hansen, P., Iversen, S., & Brammer, M. (2000). Crossmodal integration of non-speech audio-visual stimuli. *NeuroImage*, *11*(5), S727. https://doi.org/10.1016/S1053-8119(00)91657-4

Calvert, G., Spence, C., & Stein, B. E. (2004). The handbook of multisensory processes. *The Handbook of Multisensory Processes*, 933. https://doi.org/nicht verfügbar?

Caminha, R. C., & Lampreia, C. (2012). Findings on sensory deficits in autism: Implications for understanding the disorder. *Psychology & Neuroscience*, *5*(2), 231–237. https://doi.org/10.3922/j.psns.2012.2.14

Cappozzo, A., Catani, F., Della Croce, U., & Leardini, A. (1995). Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clinical Biomechanics*. https://doi.org/10.1016/0268-0033(95)91394-T

Cascio, C. J., Foss-Feig, J. H., Burnette, C. P., Heacock, J. L., & Cosby, a. a. (2012). The rubber hand illusion in children with autism spectrum disorders: delayed influence of combined tactile and visual input on proprioception. *Autism*, *16*, 406–419. https://doi.org/10.1177/1362361311430404

Cascio, C., McGlone, F., Folger, S., Tannan, V., Baranek, G., Pelphrey, K. A., & Essick, G. (2008). Tactile perception in adults with autism: A multidimensional psychophysical study. *Journal of Autism and Developmental Disorders*, *38*(1), 127–137. https://doi.org/10.1007/s10803-007-0370-8

Cascio, Carissa J., Gu, C., Schauder, K. B., Key, A. P., & Yoder, P. (2015). Somatosensory Event-Related Potentials and Association with Tactile Behavioral Responsiveness Patterns in Children with ASD. *Brain Topography*, *28*(6), 895–903. https://doi.org/10.1007/s10548-015-0439-1

Cascio, M. A., Weiss, J. A., & Racine, E. (2020). Person-oriented ethics for autism research: Creating best practices through engagement with autism and autistic communities. *Autism*, *24*(7), 1676–1690. https://doi.org/10.1177/1362361320918763

Cassam, Q. (1997). *Self and World* (1st ed.). Clarendon Press.

Centers for Disease Control and Prevention. (2013). *CDC - Data and Statistics, Autism Spectrum Disorders - NCBDDD*. Center for Disease Control.

Chamberlain, R., McManus, I. C., Riley, H., Rankin, Q., & Brunswick, N. (2013). Local processing enhancements associated with superior observational drawing are due to enhanced perceptual functioning, not weak central coherence. *Quarterly Journal of Experimental Psychology*, *66*(7), 1448–1466. https://doi.org/10.1080/17470218.2012.750678

Chaminade, T., Meltzoff, A. N., & Decety, J. (2005). An fMRI study of imitation: Action representation and body schema. *Neuropsychologia*, *43*(1), 115–127. https://doi.org/10.1016/j.neuropsychologia.2004.04.026

Charman, T., Swettenham, J., Baron-Cohen, S., Cox, A., Baird, G., & Drew, A. (1997). Infants with autism: an investigation of empathy, pretend play, joint attention, and imitation. *Developmental Psychology*. https://doi.org/10.1037/0012-1649.33.5.781

Chan, J. S., Langer, A., & Kaiser, J. (2016). Temporal integration of multisensory stimuli in autism spectrum disorder: a predictive coding perspective. *Journal of Neural Transmission*, *123*(8), 917–923. https://doi.org/10.1007/s00702-016-1587-5

Chen, Y., Norton, D. J., McBain, R., Gold, J., Frazier, J. A., & Coyle, J. T. (2012). Enhanced local processing of dynamic visual information in autism: Evidence from speed discrimination. *Neuropsychologia*, *50*(5), 733–739. https://doi.org/10.1016/j.neuropsychologia.2012.01.007

Chevallier, C., Parish-Morris, J., Mcvey, A., Rump, K. M., Sasson, N. J., Herrington, J. D., & Schultz, R. T. (2015). Measuring social attention and motivation in autism spectrum disorder using eye-tracking: Stimulus type matters. *Autism Research*. https://doi.org/10.1002/aur.1479

Chlebowski, C., Green, J. A., Barton, M. L., & Fein, D. (2010). Using the Childhood Autism Rating Scale to Diagnose Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *40*(7), 787–799. https://doi.org/10.1007/s10803-009-0926-x

Chouinard, P. A., Noulty, W. A., Sperandio, I., & Landry, O. (2013). Global processing during the M??ller-Lyer illusion is distinctively affected by the degree of autistic traits in the typical population. *Experimental Brain Research*, *230*(2), 219–231. https://doi.org/10.1007/s00221-013-3646-6

Churches, O., Wheelwright, S., Baron-Cohen, S., & Ring, H. (2010). The N170 is not modulated by attention in autism spectrum conditions. *NeuroReport*, *21*(6), 399–403. https://doi.org/10.1097/WNR.0b013e328334311b

Constantino, J. N., & Charman, T. (2012). Gender Bias, Female Resilience, and the Sex Ratio in Autism. *Journal of the American Academy of Child & Adolescent Psychiatry*, *51*(8), 756–758. https://doi.org/10.1016/j.jaac.2012.05.017

Constantino, J. N., & Todd, R. D. (2003). Autistic Traits in the General Population. *Archives of General Psychiatry*, *60*(5), 524. https://doi.org/10.1001/archpsyc.60.5.524

Cook, J., Barbalat, G., & Blakemore, S.-J. (2012). Top-down modulation of the perception of other people in schizophrenia and autism. *Frontiers in Human Neuroscience*. https://doi.org/10.3389/fnhum.2012.00175

Corbett, B. A., Constantine, L. J., Hendren, R., Rocke, D., & Ozonoff, S. (2009). Examining executive functioning in children with autism spectrum disorder, attention deficit hyperactivity disorder and typical development. *Psychiatry Research*. https://doi.org/10.1016/j.psychres.2008.02.005

Coskun, M. A., Varghese, L., Reddoch, S., Castillo, E. M., Pearson, D. A., Loveland, K. A., Papanicolaou, A. C., & Sheth, B. R. (2009). How somatic cortical maps differ in autistic and typical brains. *NeuroReport*, *20*(2), 175–179. https://doi.org/10.1097/WNR.0b013e32831f47d1

Cossu, G., Boria, S., Copioli, C., Bracceschi, R., Giuberti, V., Santelli, E., & Gallese, V. (2012). Motor representation of actions in children with autism. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0044779

Crawford, J. R., & Henry, J. D. (2004). The Positive and Negative Affect Schedule (PANAS): Construct validity, measurement properties and normative data in a large non-clinical sample. *British Journal of Clinical Psychology*, *43*(3), 245–265. https://doi.org/10.1348/0144665031752934

Dakin, S., & Frith, U. (2005). Vagaries of Visual Perception in Autism. *Neuron*, *48*(3), 497–507. https://doi.org/10.1016/j.neuron.2005.10.018

Dawson, G., & Watling, R. (2000). Interventions to facilitate auditory, visual, and motor integration in autism: A review of the evidence. In *Journal of Autism and Developmental Disorders* (Vol. 30, Issue 5, pp. 415–421). https://doi.org/10.1023/A:1005547422749

Dawson, G., Bernier, R., & Ring, R. H. (2012). Social attention: A possible early indicator of efficacy in autism clinical trials. *Journal of Neurodevelopmental Disorders*. https://doi.org/10.1186/1866-1955-4-11

De Gelder, B., & Bertelson, P. (2003). Multisensory integration, perception and ecological validity. *Trends in Cognitive Sciences*, *7*(10), 460–467. https://doi.org/10.1016/j.tics.2003.08.014

Daprati, E., Sirigu, A., & Nico, D. (2019). Remembering actions without proprioception. *Cortex*, *113*, 29–36. https://doi.org/10.1016/j.cortex.2018.11.020

De Gelder, B., & Bertelson, P. (2003). Multisensory integration, perception and ecological validity. In *Trends in Cognitive Sciences* (Vol. 7, Issue 10, pp. 460–467). https://doi.org/10.1016/j.tics.2003.08.014

De Jaegher, H. (2013a). Embodiment and sense-making in autism. *Frontiers in Integrative Neuroscience*. https://doi.org/10.3389/fnint.2013.00015

De Jaegher, H. (2013b). Rigid and fluid interactions with institutions. *Cognitive Systems Research*. https://doi.org/10.1016/j.cogsys.2013.03.002

de Jonge, M. V., Kemner, C., de Haan, E. H., Coppens, J. E., van den Berg, T. J. T. P., & van Engeland, H. (2007). Visual information processing in high-functioning individuals with autism spectrum disorders and their parents. *Neuropsychology*, *21*(1), 65–73. https://doi.org/10.1037/0894-4105.21.1.65

Deschamps, P.K.H., Coppes, L., Kenemans, J.L. (2015). Electromyographic Responses to Emotional Facial Expressions in 6–7 Year Old's with Autism Spectrum Disorders. *J Autism Dev Disorder* 45**,** 354–362. https://doi.org/10.1007/s10803-013-1890-z

Diedrichsen, J., Shadmehr, R., & Ivry, R. B. (2010). The coordination of movement: optimal feedback control and beyond. In *Trends in Cognitive Sciences*. https://doi.org/10.1016/j.tics.2009.11.004

Dinstein, I., Heeger, D. J., Lorenzi, L., Minshew, N. J., Malach, R., & Behrmann, M. (2012). Unreliable Evoked Responses in Autism. *Neuron*. https://doi.org/10.1016/j.neuron.2012.07.026

Donnellan, A. M., Hill, D. H., & Leary, M. R. (2012). Rethinking autism: Implications of sensory and movement differences for understanding and support. *Frontiers in Integrative Neuroscience*. https://doi.org/10.3389/fnint.2012.00124

Donohue, S. E., Darling, E. F., & Mitroff, S. R. (2012). Links between multisensory processing and autism. *Experimental Brain Research*, *222*(4), 377–387. https://doi.org/10.1007/s00221-012-3223-4

Dowd, A. M., McGinley, J. L., Taffe, J. R., & Rinehart, N. J. (2012). Do planning and visual integration difficulties underpin motor dysfunction in autism? A kinematic study of young children with autism. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-011-1385-8

Driver, J., & Spence, C. (1998). Crossmodal attention. In *Current Opinion in Neurobiology* (Vol. 8, Issue 2, pp. 245–253). https://doi.org/10.1016/S0959-4388(98)80147-5

Dukelow, S. P., Herter, T. M., Moore, K. D., Demers, M. J., Glasgow, J. I., Bagg, S. D., Norman, K. E., & Scott, S. H. (2010). Quantitative assessment of limb position sense following stroke. *Neurorehabilitation and Neural Repair*. https://doi.org/10.1177/1545968309345267

Elam, J. T., Graney, M. J., Beaver, T., El Derwi, D., Applegate, W. B., & Miller, S. T. (1991). Comparison of subjective ratings of function with observed functional ability of frail older persons. *American Journal of Public Health*, *81*(9), 1127–1130. https://doi.org/10.2105/AJPH.81.9.1127

Eliane, D., Jan, W., & Marcel, B. (2015). Action-based touch simulation in high functioning autism: Can compromised self-other distinction abilities link social and sensory problems in the autism spectrum? *Frontiers in Neuroscience*, *9*, 254–271. https://doi.org/10.3389/conf.fnins.2015.89.00083

Elliott, R. (2003). Executive functions and their disorders. *British Medical Bulletin*, *65*(1), 49–59. https://doi.org/10.1093/bmb/65.1.49

Elwin, M., Ek, L., Schröder, A., & Kjellin, L. (2012). Autobiographical Accounts of Sensing in Asperger Syndrome and High-Functioning Autism. *Archives of Psychiatric Nursing*. https://doi.org/10.1016/j.apnu.2011.10.003

Ernst, M. O., & Bülthoff, H. H. (2004). Merging the senses into a robust percept. *Trends in Cognitive Sciences*, *8*(4), 162–169. https://doi.org/10.1016/j.tics.2004.02.002

Fabbri-Destro, M., Cattaneo, L., Boria, S., & Rizzolatti, G. (2009). Planning actions in autism. *Experimental Brain Research*. https://doi.org/10.1007/s00221-008-1578-3

Farmer, H., Tajadura-Jiménez, A., & Tsakiris, M. (2012). Beyond the colour of my skin: How skin colour affects the sense of body-ownership. *Consciousness and Cognition*, *21*(3), 1242–1256. https://doi.org/10.1016/j.concog.2012.04.011

Fazlioğlu, Y. ş., & Baran, G. (2008). A Sensory Integration Therapy Program on Sensory Problems for Children with Autism. *Perceptual and Motor Skills*, *106*(2), 415–422. https://doi.org/10.2466/pms.106.2.415-422

Fitch, A., Fein, D. A., & Eigsti, I. M. (2015). Detail and Gestalt Focus in Individuals with Optimal Outcomes from Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *45*(6), 1887–1896. https://doi.org/10.1007/s10803-014-2347-8

Foss-Feig, J. H., Heacock, J. L., & Cascio, C. J. (2012). Tactile responsiveness patterns and their association with core features in autism spectrum disorders. *Research in Autism Spectrum Disorders*, *6*(1), 337–344. https://doi.org/10.1016/j.rasd.2011.06.007

Foss-Feig, J. H., Kwakye, L. D., Cascio, C. J., Burnette, C. P., Kadivar, H., Stone, W. L., & Wallace, M. T. (2010). An extended multisensory temporal binding window in autism spectrum disorders. *Experimental Brain Research*, *203*(2), 381–389. https://doi.org/10.1007/s00221-010-2240-4

Fournier, K. A., Hass, C. J., Naik, S. K., Lodha, N., & Cauraugh, J. H. (2010). Motor coordination in autism spectrum disorders: A synthesis and meta-analysis. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-010-0981-3

Foxe, J. J., & Molholm, S. (2009). Ten years at the multisensory forum: Musings on the evolution of a field. *Brain Topography*, *21*(3–4), 149–154. https://doi.org/10.1007/s10548-009-0102-9

Freeth, M., Sheppard, E., Ramachandran, R., & Milne, E. (2013). A Cross-Cultural Comparison of Autistic Traits in the UK, India and Malaysia. *Journal of Autism and Developmental Disorders*, *43*(11), 2569–2583. https://doi.org/10.1007/s10803-013-1808-9

Frith, U. (1989). Autism explain the enigma. In *Oxford*.

Frith, Uta, & Happé, F. (1994a). Autism: beyond "theory of mind." *Cognition*, *50*(1–3), 115–132. https://doi.org/10.1016/0010-0277(94)90024-8

Frith, Uta, & Happé, F. (1994b). Frith & Happe 1994 Cognition Theory Weak Centrel Coherence.pdf. *Cognition*, *50*, 115–132.

Funahashi, S. (2007). Representation and brain. In *Representation and Brain*. https://doi.org/10.1007/978-4-431-73021-7

Galea, V. (2012). No Proprioceptive Deficits in Autism Despite Movement-Related Sensory and Execution Impairments. *Yearbook of Sports Medicine*, *2012*, 373–374. https://doi.org/10.1016/j.yspm.2012.03.013

Gallagher, S. (2000). Philosophical conceptions of the self: implications for cognitive science. *Trends in Cognitive Sciences*, *4*(1), 14–21. https://doi.org/10.1016/s1364-6613(99)01417-5

Gallese, V. (2006). Mirror neurons and intentional attunement: commentary on Olds. *Journal of the American Psychoanalytic Association*, *54*(1), 47–57. https://doi.org/10.1016/j.brainres.2006.01.054

Gallese, V., Keysers, C. & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences*, *8*(9), 396–403. https://doi.org/10.1016/j.tics.2004.07.002

Gelder, B. De, Vroomen, J., & van der Heide, L. (1991). Face recognition and lip-reading in autism. *European Journal of Cognitive Psychology*, *3*(1), 69–86. https://doi.org/10.1080/09541449108406220

Gepner, B. (2004). Autism, Movement, and Facial Processing. *American Journal of Psychiatry*. https://doi.org/10.1176/appi.ajp.161.9.1719

Gepner, B., & Mestre, D. R. (2002). Letter to the editor: Teaching the illusion of facilitated communication. *Journal Of Autism And Developmental Disorders*.

Geschwind, D. H., & Levitt, P. (2007). Autism spectrum disorders: developmental disconnection syndromes. In *Current Opinion in Neurobiology*. https://doi.org/10.1016/j.conb.2007.01.009

Glazebrook, C. M., Gonzalez, D., & Elliott, D. (2007). The role of vision for online control of aiming movements in persons with autism. *Journal of Sport & Exercise Psychology*.

Glazebrook, C., Gonzalez, D., Hansen, S., & Elliott, D. (2009). The role of vision for online control of manual aiming movements in persons with autism spectrum disorders. *Autism*. https://doi.org/10.1177/1362361309105659

Goris, J., Brass, M., Cambier, C., Delplanque, J., Wiersema, J. R., & Braem, S. (2019). The Relation Between Preference for Predictability and Autistic Traits. *Autism Research*, *13*(7), 1144–1154. https://doi.org/10.1002/aur.2244

Gowen, E. (2012). Imitation in autism: Why action kinematics matter. *Frontiers in Integrative Neuroscience*. https://doi.org/10.3389/fnint.2012.00117

Gowen, E., & Hamilton, A. (2013). Motor abilities in autism: A review using a computational context. In *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-012-1574-0

Gowen, E., & Miall, R. C. (2005). Behavioural aspects of cerebellar function in adults with Asperger syndrome. *Cerebellum*. https://doi.org/10.1080/14734220500355332

Green, D., Charman, T., Pickles, A., Chandler, S., Loucas, T., Simonoff, E., & Baird, G. (2009). Impairment in movement skills of children with autistic spectrum disorders. *Developmental Medicine and Child Neurology*. https://doi.org/10.1111/j.1469-8749.2008.03242.x

Greenfield, K., Ropar, D., Smith, A. D., Carey, M., & Newport, R. (2015). Visuo-tactile integration in autism: atypical temporal binding may underlie greater reliance on proprioceptive information. *Molecular Autism*, *6*(1), 51. https://doi.org/10.1186/s13229-015-0045-9

Gregory, B. L., & Plaisted-Grant, K. C. (2016). The Autism-Spectrum Quotient and Visual Search: Shallow and Deep Autistic Endophenotypes. *Journal of Autism and Developmental Disorders*, *46*(5), 1503–1512. https://doi.org/10.1007/s10803-013-1951-3

Grice, S. J., Spratling, M. W., Karmiloff-Smith, A., Halit, H., Csibra, G., De Haan, M., & Johnson, M. H. (2001). Disordered visual processing and oscillatory brain activity in autism and Williams syndrome. *NeuroReport*, *12*(12), 2697–2700. https://doi.org/10.1097/00001756-200108280-00021

Güçlü, B., Tanidir, C., Mukaddes, N. M., & Ünal, F. (2007). Tactile sensitivity of normal and autistic children. *Somatosensory and Motor Research*, *24*(1–2), 21–33. https://doi.org/10.1080/08990220601179418

Guerraz, M., Provost, S., Narison, R., Brugnon, A., Virolle, S., & Bresciani, J. P. (2012). Integration of visual and proprioceptive afferents in kinesthesia. *Neuroscience*, *223*, 258–268. https://doi.org/10.1016/j.neuroscience.2012.07.059

Haigh, S. M., Heeger, D. J., Dinstein, I., Minshew, N., & Behrmann, M. (2015). Cortical Variability in the Sensory-Evoked Response in Autism. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-014-2276-6

Hames, E. C., Murphy, B., Rajmohan, R., Anderson, R. C., Baker, M., Zupancic, S., O'Boyle, M., & Richman, D. (2016). Visual, Auditory, and Cross Modal Sensory Processing in Adults with Autism: An EEG Power and BOLD fMRI Investigation. *Frontiers in Human Neuroscience*, *10*. https://doi.org/10.3389/fnhum.2016.00167

Hannant, P., Cassidy, S., Tavassoli, T., & Mann, F. (2016). Sensorimotor difficulties are associated with the severity of autism spectrum conditions. *Frontiers in Integrative Neuroscience*. https://doi.org/10.3389/fnint.2016.00028

Happé, F. (1999). Autism: Cognitive deficit or cognitive style? In *Trends in Cognitive Sciences* (Vol. 3, Issue 6, pp. 216–222). https://doi.org/10.1016/S1364-6613(99)01318-2

Happe, F. (2005). The Weak Central Coherence Account of Autism. In *Handbook of autism and pervasive developmental disorders, Vol. 1: Diagnosis, development, neurobiology, and behavior (3rd ed.).* (pp. 640–649). https://doi.org/10.1002/9780470939345.ch24

Happé, F. G. E., & Booth, R. D. L. (2008). The Power of the Positive: Revisiting Weak Coherence in Autism Spectrum Disorders. *Quarterly Journal of Experimental Psychology*, *61*(1), 50–63. https://doi.org/10.1080/17470210701508731

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. In *Journal of Autism and Developmental Disorders* (Vol. 36, Issue 1, pp. 5–25). https://doi.org/10.1007/s10803-005-0039-0

Happé, F., Ronald, A., & Plomin, R. (2006a). Time to give up on a single explanation for autism. In *Nature Neuroscience* (Vol. 9, Issue 10, pp. 1218–1220). https://doi.org/10.1038/nn1770

Happé, F., Ronald, A., & Plomin, R. (2006b). Time to give up on a single explanation for autism. *Nature Neuroscience*, *9*(10), 1218–1220. https://doi.org/10.1038/nn1770

Haswell, C. C., Izawa, J., R Dowell, L., H Mostofsky, S., & Shadmehr, R. (2009). Representation of internal models of action in the autistic brain. *Nature Neuroscience*. https://doi.org/10.1038/nn.2356

Hay, J. C., Pick, H. L., & Ikeda, K. (1965). Visual capture produced by prism spectacles. *Psychonomic Science*, *2*(1–12), 215–216. https://doi.org/10.3758/BF03343413

Hense, M., Badde, S., Köhne, S., Dziobek, I., & Röder, B. (2019). Visual and Proprioceptive Influences on Tactile Spatial Processing in Adults with Autism Spectrum Disorders. *Autism Research*. https://doi.org/10.1002/aur.2202

Hermans, E. J., van Wingen, G., Bos, P. A., Putman, P., & van Honk, J. (2009). Reduced spontaneous facial mimicry in women with autistic traits. *Biological Psychology*, *80*(3), 348–353. https://doi.org/10.1016/j.biopsycho.2008.12.002

Hill, E. L., & Frith, U. (2003). Understanding autism: insights from mind and brain. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *358*(1430), 281–289. https://doi.org/10.1098/rstb.2002.1209

Hill, Elisabeth L. (2004). Evaluating the theory of executive dysfunction in autism. In *Developmental Review* (Vol. 24, Issue 2, pp. 189–233). https://doi.org/10.1016/j.dr.2004.01.001

Hillock-Dunn, A., & Wallace, M. T. (2012). Developmental changes in the multisensory temporal binding window persist into adolescence. *Developmental Science*, *15*(5), 688–696. https://doi.org/10.1111/j.1467-7687.2012.01171.x

Hillock, A. R., Powers, A. R., & Wallace, M. T. (2011). Binding of sights and sounds: Age-related changes in multisensory temporal processing. *Neuropsychologia*, *49*(3), 461–467. https://doi.org/10.1016/j.neuropsychologia.2010.11.041

Hochberg, L. R., Bacher, D., Jarosiewicz, B., Masse, N. Y., Simeral, J. D., Vogel, J., Haddadin, S., Liu, J., Cash, S. S., Van Der Smagt, P., & Donoghue, J. P. (2012). Reach and grasp by people with tetraplegia using a neurally controlled robotic arm. *Nature*. https://doi.org/10.1038/nature11076

Hoekstra, R. a, Bartels, M., Verweij, C. J. H., & Boomsma, D. I. (2007). Heritability of autistic traits in the general population. *Archives of Pediatrics & Adolescent Medicine*, *161*(4), 372–377. https://doi.org/10.1001/archpedi.161.4.372

Hohwy, J., & Paton, B. (2010). Explaining Away the Body: Experiences of Supernaturally Caused Touch and Touch on Non-Hand Objects within the Rubber Hand Illusion. *PLoS ONE*, *5*(2), e9416. https://doi.org/10.1371/journal.pone.0009416

Holmes, N. P., & Spence, C. (2005). Visual bias of unseen hand position with a mirror: spatial and temporal factors. *Experimental Brain Research*, *166*(3–4), 489–497. https://doi.org/10.1007/s00221-005-2389-4

Holst-Wolf, J. M., Yeh, I.-L., & Konczak, J. (2016). Development of Proprioceptive Acuity in Typically Developing Children: Normative Data on Forearm Position Sense. *Frontiers in Human Neuroscience*, *10*, 121–155. https://doi.org/10.3389/fnhum.2016.00436

Hoy, J. A., Hatton, C., & Hare, D. (2004). Weak central coherence: A cross-domain phenomenon specific to autism? *Autism*, *8*(3), 267–281. https://doi.org/10.1177/1362361304045218

Hurst, R. M., Mitchell, J. T., Kimbrel, N. A., Kwapil, T. K., & Nelson-Gray, R. O. (2007). Examination of the reliability and factor structure of the Autism Spectrum Quotient

(AQ) in a non-clinical sample. *Personality and Individual Differences*, *43*(7), 1938–1949. https://doi.org/10.1016/j.paid.2007.06.012

Iarocci, G., Rombough, A., Yager, J., Weeks, D. J., & Chua, R. (2010). Visual influences on speech perception in children with autism. *Autism*, *14*(4), 305–320. https://doi.org/10.1177/1362361309353615

Ide, M., & Wada, M. (2016). Periodic Visuotactile Stimulation Slowly Enhances the Rubber Hand Illusion in Individuals with High Autistic Traits. *Frontiers in Integrative Neuroscience*, *10*, 151–162. https://doi.org/10.3389/fnint.2016.00021

Irwin, J. R., Tornatore, L. A., Brancazio, L., & Whalen, D. H. (2011). Can children with autism spectrum disorders "hear" a speaking face? *Child Development*, *82*(5), 1397–1403. https://doi.org/10.1111/j.1467-8624.2011.01619.x

Izawa, J., Criscimagna-Hemminger, S. E., & Shadmehr, R. (2012). Cerebellar Contributions to Reach Adaptation and Learning Sensory Consequences of Action. *Journal of Neuroscience*, *32*(12), 4230–4239. https://doi.org/10.1523/jneurosci.6353-11.2012

Izawa, J., Pekny, S. E., Marko, M. K., Haswell, C. C., Shadmehr, R., & Mostofsky, S. H. (2012). Motor Learning Relies on Integrated Sensory Inputs in ADHD, but Over-Selectively on Proprioception in Autism Spectrum Conditions. *Autism Research*, *5*(2), 124–136. https://doi.org/10.1002/aur.1222

Jackson, S. L. J., & Dritschel, B. (2016). Modeling the impact of social problem-solving deficits on depressive vulnerability in the broader autism phenotype. *Research in Autism Spectrum Disorders*, *21*, 128–138. https://doi.org/10.1016/j.rasd.2015.10.002

Jennifer, C., Gidley, L., Amy, J. B., Opher. D., Reza, S., Stewart H. M., (2008) Acquisition of internal models of motor tasks in children with autism, *Brain*, Volume 131, Issue 11, Pages 2894-2903, https://doi.org/10.1093/brain/awn226

Jones, M. C., & Johnston, D. W. (2000). A critical review of the relationship between perception of the work environment, coping and mental health in trained nurses, and patient outcomes. *Clinical Effectiveness in Nursing*, *4*(2), 75–85. https://doi.org/10.1054/cein.2000.0109

Kammers, M. P. ., de Vignemont, F., Verhagen, L., & Dijkerman, H. c. (2009). The rubber hand illusion in action. *Neuropsychologia*, *47*(1), 204–211. https://doi.org/10.1016/j.neuropsychologia.2008.07.028

Kanner L. (1943). Autistic disturbances of affective contact. *Nervous Child* **2**, 217-250

Kalckert, A., & Ehrsson, H. H. (2014). The moving rubber hand illusion revisited: Comparing movements and visuotactile stimulation to induce illusory ownership. *Consciousness and Cognition*, *26*, 117–132. https://doi.org/10.1016/j.concog.2014.02.003

Kanwisher, N., & Yovel, G. (2006). The fusiform face area: a cortical region specialized for the perception of faces. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *361*(1476), 2109–2128. https://doi.org/10.1098/rstb.2006.1934

Kaufman, A. S. (1983). Test Review: Wechsler, D. Manual for the Wechsler Adult Intelligence Scale, Revised. New York: Psychological Corporation, 1981. In *Journal of Psychoeducational Assessment* (Vol. 1, Issue 3, pp. 309–313). https://doi.org/10.1177/073428298300100310

Kern, J. K., Trivedi, M. H., Garver, C. R., Grannemann, B. D., Andrews, A. A., Savla, J. S., Johnson, D. G., Mehta, J. A., & Schroeder, J. L. (2006). The pattern of sensory processing abnormalities in autism. *Autism*, *10*(5), 480–494. https://doi.org/10.1177/1362361306066564

Kern, J. K., Trivedi, M. H., Grannemann, B. D., Garver, C. R., Johnson, D. G., Andrews, A. A., Savla, S. J., Mehta, J. A., & Schroeder, J. L. (2007). Sensory correlations in autism. *Autism*, *11*(2), 123–134. https://doi.org/10.1177/1362361307075702

Kilteni, K., Maselli, A., Kording, K. P., & Slater, M. (2015). Over my fake body: body ownership illusions for studying the multisensory basis of own-body perception. *Frontiers in Human Neuroscience*, *9*, 111–123. https://doi.org/10.3389/fnhum.2015.00141

Kleberg, J. L. (2014). Resting state arousal and brain activity in Autism Spectrum Disorder. *Journal of Neurophysiology*.

Koh, H. C., Milne, E., & Dobkins, K. (2010). Spatial contrast sensitivity in adolescents with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *40*(8), 978–987. https://doi.org/10.1007/s10803-010-0953-7

Kopp, S., Beckung, E., & Gillberg, C. (2010). Developmental coordination disorder and other motor control problems in girls with autism spectrum disorder and/or attention-deficit/hyperactivity disorder. *Research in Developmental Disabilities*. https://doi.org/10.1016/j.ridd.2009.09.017

Kurita, H., Koyamoto, T., & Osada, H. (2005). Autism-Spectrum Quotient-Japanese version and its short forms for screening normally intelligent persons with pervasive developmental disorders. *Psychiatry and Clinical Neurosciences, 59*(4), 490–496. https://doi.org/10.1111/j.1440-1819.2005.01403.x

Kunihira, Y., Senju, A., Dairoku, H., Wakabayashi, A., & Hasegawa, T. (2006). 'Autistic' Traits in Non-Autistic Japanese Populations: Relationships with Personality Traits and Cognitive Ability. *Journal of Autism and Developmental Disorders, 36*(4), 553–566. https://doi.org/10.1007/s10803-006-0094-1

Kwakye, L. D., Foss-Feig, J. H., Cascio, C. J., Stone, W. L., & Wallace, M. T. (2011). Altered Auditory and Multisensory Temporal Processing in Autism Spectrum Disorders. *Frontiers in Integrative Neuroscience*, *4*, 211–222. https://doi.org/10.3389/fnint.2010.00129

Làdavas, E., & Pavani, F. (1998). Neuropsychological evidence of the functional integration of visual, auditory and proprioceptive spatial maps. *NeuroReport*, *9*(6), 1195–1200. https://doi.org/10.1097/00001756-199804200-00043

Lajoie, Y., Paillard, J., Teasdale, N., Bard, C., Fleury, M., Forget, R., & Lamarre, Y. (1992). Mirror drawing in a deafferented patient and normal subjects: visuoproprioceptive conflict. *Neurology*, *42*(5), 1104–1106. https://doi.org/10.1212/WNL.42.5.1104

Landa, R. J., Haworth, J. L., & Nebel, M. B. (2016). Ready, set, go! Low anticipatory response during a dyadic task in infants at high familial risk for autism. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2016.00721

Landa, R., & Garrett-Mayer, E. (2006). Development in infants with autism spectrum disorders: A prospective study. *Journal of Child Psychology and Psychiatry and Allied Disciplines*. https://doi.org/10.1111/j.1469-7610.2006.01531.x

Lawson, R. P., Rees, G., & Friston, K. J. (2014). An aberrant precision account of autism. *Frontiers in Human Neuroscience*, *8*, 121–135. https://doi.org/10.3389/fnhum.2014.00302

Leekam, S. R., Nieto, C., Libby, S. J., Wing, L., & Gould, J. (2007). Describing the sensory abnormalities of children and adults with autism. *Journal of Autism and Developmental Disorders*, *37*(5), 894–910. https://doi.org/10.1007/s10803-006-0218-7

Leitner, Y. (2014). The Co-Occurrence of Autism and Attention Deficit Hyperactivity Disorder in Children â€“ What Do We Know? *Frontiers in Human Neuroscience*, *8*. https://doi.org/10.3389/fnhum.2014.00268

Lewkowicz, D. (2012). Development of multisensory temporal perception. In *The neural bases of multisensory processes* (p. Chapter 17). http://www.ncbi.nlm.nih.gov/pubmed/22593879

Lira, M., Egito, J. H., Dall'Agnol, P. A., Amodio, D. M., Gonçalves, Ó. F., & Boggio, P. S. (2017). The influence of skin colour on the experience of ownership in the rubber hand illusion. *Scientific Reports*, *7*(1), 165–192. https://doi.org/10.1038/s41598-017-16137-3

Lloyd, D. M. (2007). Spatial limits on referred touch to an alien limb may reflect boundaries of visuo-tactile peripersonal space surrounding the hand. *Brain and Cognition*, *64*(1), 104–109. https://doi.org/10.1016/j.bandc.2006.09.013

Longo, M. R. (2017). Hand Posture Modulates Perceived Tactile Distance. *Scientific Reports*, *7*(1), 251–262. https://doi.org/10.1038/s41598-017-08797-y

Lovaas, I., Newsom, C., & Hickman, C. (1987). Self-stimulatory behavior and perceptual reinforcement. *Journal of Applied Behavior Analysis*, *20*(1), 45–68. https://doi.org/10.1901/jaba.1987.20-45

Low, J., Goddard, E., & Melser, J. (2009). Generativity and imagination in autism spectrum disorder: Evidence from individual differences in children's impossible entity drawings.

British Journal of Developmental Psychology, *27*(2), 425–444. https://doi.org/10.1348/026151008X334728

Lundqvist, L. O., & Lindner, H. (2017). Is the Autism-Spectrum Quotient a Valid Measure of Traits Associated with the Autism Spectrum? A Rasch Validation in Adults with and Without Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *47*(7), 2080–2091. https://doi.org/10.1007/s10803-017-3128-y

Lundström, S. (2012). Autism Spectrum Disorders and Autisticlike Traits. *Archives of General Psychiatry*, *69*(1), 46. https://doi.org/10.1001/archgenpsychiatry.2011.144

Macdonald, M., Lord, C., & Ulrich, D. (2013). The relationship of motor skills and adaptive behavior skills in young children with autism spectrum disorders. *Research in Autism Spectrum Disorders*. https://doi.org/10.1016/j.rasd.2013.07.020

Maekawa, T., Tobimatsu, S., Inada, N., Oribe, N., Onitsuka, T., Kanba, S., & Kamio, Y. (2011). Top-down and bottom-up visual information processing of non-social stimuli in high-functioning autism spectrum disorder. *Research in Autism Spectrum Disorders*, *5*(1), 201–209. https://doi.org/10.1016/j.rasd.2010.03.012

Makin, T. R., Holmes, N. P., & Ehrsson, H. H. (2008). On the other hand: Dummy hands and peripersonal space. *Behavioural Brain Research*, *191*(1), 1–10. https://doi.org/10.1016/j.bbr.2008.02.041

Makin, T. R., Holmes, N. P., & Ehrsson, H. H. (2008). On the other hand: Dummy hands and peripersonal space. In *Behavioural Brain Research* (Vol. 191, Issue 1, pp. 1–10). https://doi.org/10.1016/j.bbr.2008.02.041

Mandy, W. P. L., & Skuse, D. H. (2008). Research Review: What is the association between the social-communication element of autism and repetitive interests, behaviours and activities? *Journal of Child Psychology and Psychiatry*, *49*(8), 795–808. https://doi.org/10.1111/j.1469-7610.2008.01911.x

Manning, C., Morgan, M. J., Allen, C. T. W., & Pellicano, E. (2017). Susceptibility to Ebbinghaus and Müller-Lyer illusions in autistic children: a comparison of three different methods. *Molecular Autism*, *8*, 16. https://doi.org/10.1186/s13229-017-0127-y

Marco, Elysa J., Hinkley, L. B. N., Hill, S. S., & Nagarajan, S. S. (2011). Sensory processing in autism: A review of neurophysiologic findings. *Pediatric Research*, *69*(5 PART 2). https://doi.org/10.1203/PDR.0b013e3182130c54

Marco, Elysa Jill, Barett, L., Hinkley, L. B. N., Hill, S. S., & Nagarajan, S. S. (2012). Sensory Processing in Autism: A Review of Neurophysiologic Findings. *Pediatrics*, *69*, 1–14. https://doi.org/10.1203/PDR.0b013e3182130c54.Sensory

Marco, Elysa Jill, Hinkley, L. B. N., Hill, S. S., & Nagarajan, S. S. (2011). Sensory Processing in Autism: A Review of Neurophysiologic Findings. *Pediatric Research*, *69*(5 Pt 2), 48R-54R. https://doi.org/10.1203/PDR.0b013e3182130c54

Mari, M., Castiello, U., Marks, D., Marraffa, C., & Prior, M. (2003). The reach-to-grasp movement in children with autism spectrum disorder. *Philosophical Transactions of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rstb.2002.1205

Marko, M. K., Crocetti, D., Hulst, T., Donchin, O., Shadmehr, R., & Mostofsky, S. H. (2015). Behavioural and neural basis of anomalous motor learning in children with autism. *Brain*, *138*(3), 784–797. https://doi.org/10.1093/brain/awu394

Massaro, D. W., & Bosseler, A. (2003). Perceiving speech by ear and eye: Multimodal integration by children with autism. *Journal of Developmental and Learning Disorders*, *7*(October), 111–144.

Masterton, B. A., & Biederman, G. B. (1983). Proprioceptive versus visual control in autistic children. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/BF01531815

Matsushima, K., & Kato, T. (2013). Social interaction and atypical sensory processing in children with autism spectrum disorders. *Hong Kong Journal of Occupational Therapy*. https://doi.org/10.1016/j.hkjot.2013.11.003

Mattila, M. L., Kielinen, M., Jussila, K., Linna, S. L., Bloigu, R., Ebeling, H., & Moilanen, I. (2007). An epidemiological and diagnostic study of Asperger syndrome according to four sets of diagnostic criteria. *Journal of the American Academy of Child and Adolescent Psychiatry*. https://doi.org/10.1097/chi.0b013e318033ff42

McCauley, R. N., & Henrich, J. (2006). Susceptibility to the Müller-Lyer Illusion, theory-neutral observation, and the diachronic penetrability of the visual input system. *Philosophical Psychology*, *19*(1), 79–101. https://doi.org/10.1080/09515080500462347

McClelland, J. L., & Ralph, M. A. L. (2015). Cognitive Neuroscience. In *International Encyclopedia of the Social & Behavioral Sciences: Second Edition*. https://doi.org/10.1016/B978-0-08-097086-8.56007-3

McGurk, H., & Macdonald, J. (1976). Hearing lips and seeing voices. *Nature*, *264*(5588), 746–748. https://doi.org/10.1038/264746a0

McKenzie, K. J., & Newport, R. (2015). Increased somatic sensations are associated with reduced limb ownership. *Journal of Psychosomatic Research*, *78*(1), 88–90. https://doi.org/10.1016/j.jpsychores.2014.11.005

Meltzoff, A. N. (2007). 'Like me': a foundation for social cognition. *Developmental Science*, *10*(1), 126–134. https://doi.org/10.1111/j.1467-7687.2007.00574.x

Meltzoff, A. N., & Moore, M. K. (1997). Explaining facial imitation: a theoretical model. *Early Development and Parenting*, *6*(3–4), 179–192. https://onlinelibrary.wiley.com/doi/abs/10.1002/%28SICI%291099-0917%28199709/12%296%3A3/4%3C179%3A%3AAID-EDP157%3E3.0.CO%3B2-R

Meltzoff, A., & Gopnik, A. (1993). The Role of Imitation in Understanding Persons and Developing a Theory of Mind. In *Understanding Other Minds* (pp. 335–66).

Merchant, K. A., Stringer, C., & Theivananthampillai, P. (2010). Relationships between Objective and Subjective Performance Ratings. *Wp*, *17*, 1–37. https://ourarchive.otago.ac.nz/bitstream/handle/10523/706/subjectivity_10-14-09_final_first_draft.pdf?sequence=2&isAllowed=y

Michel, C., Pisella, L., Halligan, P. W., Luauté, J., Rode, G., Boisson, D., & Rossetti, Y. (2003). Simulating unilateral neglect in normals using prism adaptation: Implications for theory. *Neuropsychologia*, *41*(1), 25–39. https://doi.org/10.1016/S0028-3932(02)00135-5

Milne, E., & Scope, A. (2008). Are children with autistic spectrum disorders susceptible to contour illusions? *British Journal of Developmental Psychology*, *26*(1), 91–102. https://doi.org/10.1348/026151007x202509

Ming, X., Brimacombe, M., & Wagner, G. C. (2007). Prevalence of motor impairment in autism spectrum disorders. *Brain and Development*. https://doi.org/10.1016/j.braindev.2007.03.002

Minshew, N. J., Sung, K., Jones, B. L., & Furman, J. M. (2004). Underdevelopment of the postural control system in autism. *Neurology*, *63*(11), 2056–2061. https://doi.org/10.1212/01.wnl.0000145771.98657.62

Mikkelsen, M., Wodka, E. L., Mostofsky, S. H., & Puts, N. A. J. (2018). Autism spectrum disorder in the scope of tactile processing. *Developmental Cognitive Neuroscience*, *29*, 140–150. https://doi.org/10.1016/j.dcn.2016.12.005

Mockett, S. (1993). Sensory Integration: Theory and practice. *Physiotherapy*. https://doi.org/10.1016/s0031-9406(10)60328-8

Moers, F. (2005). Discretion and bias in performance evaluation: The impact of diversity and subjectivity. *Accounting, Organizations and Society*, *30*(1), 67–80. https://doi.org/10.1016/j.aos.2003.11.001

Moore, J. W., Wegner, D. M., & Haggard, P. (2009). Modulating the sense of agency with external cues. *Consciousness and Cognition*. https://doi.org/10.1016/j.concog.2009.05.004

Mottron, L., Burack, J. a. J., Dawson, M., Soulières, I., & Hubert, B. (2001). Enhanced perceptual functioning in the development of autism. *The Development of Autism: Perspectives from Theory and Research*, *36*(January 2001), 27–43. https://doi.org/10.1007/s10803-005-0040-7

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. In *Journal of Autism and Developmental Disorders* (Vol. 36, Issue 1, pp. 27–43). https://doi.org/10.1007/s10803-005-0040-7

Moy, S., Nadler, J., Young, N., Perez, A., Holloway, L., Barboro, R., Barbaro, J., Wilson, L., Threadgill, D., & Launder, J. (2007). Mouse behavioral tasks relevant to autism: Phenotypes of 10 inbred strains. *Behavioural Brain Research, 176*(1), 4–20. https://doi.org/10.1016/j.bbr.2006.07.030

Murray, D., Lesser, M., & Lawson, W. (2005). Attention, monotropism and the diagnostic criteria for autism. *Autism*. https://doi.org/10.1177/1362361305051398

Nardini, M., Begus, K., & Mareschal, D. (2013). Multisensory uncertainty reduction for hand localization in children and adults. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(3), 773–787. https://doi.org/10.1037/a0030719

Nardini, M., Jones, P., Bedford, R., & Braddick, O. (2008). Development of Cue Integration in Human Navigation. *Current Biology*, *18*(9), 689–693. https://doi.org/10.1016/j.cub.2008.04.021

Navon, D., & Norman, J. (1983). Does global precedence reality depend on visual angle? *Journal of Experimental Psychology: Human Perception and Performance*, *9*(6), 955–965. https://doi.org/10.1037/0096-1523.9.6.955

Newport, R., & Gilpin, H. R. (2011). Multisensory disintegration and the disappearing hand trick. *Current Biology*, *21*(19). https://doi.org/10.1016/j.cub.2011.08.044

Newport, R., & Preston, C. (2010). Pulling the finger off disrupts agency, embodiment and peripersonal space. *Perception*, *39*(9), 1296–1298. https://doi.org/10.1068/p6742

Newport, R., Auty, K., Carey, M., Greenfield, K., Howard, E. M., Ratcliffe, N., Thair, H., & Themelis, K. (2015). Give it a tug and feel it grow: Extending body perception through the universal nature of illusory finger stretching. *I-Perception*, *6*(5), 1–4. https://doi.org/10.1177/2041669515599310

Newport, R., Pearce, R., & Preston, C. (2010). Fake hands in action: Embodiment and control of supernumerary limbs. *Experimental Brain Research*, *204*(3), 385–395. https://doi.org/10.1007/s00221-009-2104-y

Ngeo, J. G., Tamei, T., & Shibata, T. (2014). Continuous and simultaneous estimation of finger kinematics using inputs from an EMG-to-muscle activation model. *Journal of NeuroEngineering and Rehabilitation*. https://doi.org/10.1186/1743-0003-11-122

Nico, D., Daprati, E., Rigal, F., Parsons, L., & Sirigu, A. (2004). Left and right hand recognition in upper limb amputees. *Brain*, *127*(1), 120–132. https://doi.org/10.1093/brain/awh006

Nomi, J. S., & Uddin, L. Q. (2015). Developmental changes in large-scale network connectivity in autism. *NeuroImage: Clinical*, *7*, 732–741. https://doi.org/10.1016/j.nicl.2015.02.024

O'Neill, M., & Jones, R. S. P. (1997). Sensory-perceptual abnormalities in autism: A case for more research? *Journal of Autism and Developmental Disorders*, *27*(3), 283–294. https://doi.org/10.1023/A:1025850431170

Oldehinkel, A. J. T. (2018). Editorial: Sweet nothings - the value of negative findings for scientific progress. *Journal of Child Psychology and Psychiatry*, *59*(8), 829–830. https://doi.org/10.1111/jcpp.12952

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Oliveira, L., Mocaiber, I., David, I. A., Erthal, F., Volchan, E., & Pereira, M. G. (2013). Emotion and attention interaction: a trade-off between stimuli relevance, motivation and individual differences. *Frontiers in Human Neuroscience*. https://doi.org/10.3389/fnhum.2013.00364

Osterling, J., & Dawson, G. (1994). Early recognition of children with autism: A study of first birthday home videotapes. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/BF02172225

Palmer, C. J., Paton, B., Enticott, P. G., & Hohwy, J. (2014). 'Subtypes' in the Presentation of Autistic Traits in the General Adult Population. *Journal of Autism and Developmental Disorders*, *45*(5), 1291–1301. https://doi.org/10.1007/s10803-014-2289-1

Palmer, C. J., Paton, B., Hohwy, J., & Enticott, P. G. (2013). Movement under uncertainty: The effects of the rubber-hand illusion vary along the nonclinical autism spectrum. *Neuropsychologia*,*51*(10),1942–1951. https://doi.org/10.1016/j.neuropsychologia.2013.06.020

Papadopoulos, N., McGinley, J., Tonge, B. J., Bradshaw, J. L., Saunders, K., & Rinehart, N. J. (2012). An investigation of upper limb motor function in high functioning autism and Asperger's disorder using a repetitive Fitts' aiming task. *Research in Autism Spectrum Disorders*. https://doi.org/10.1016/j.rasd.2011.05.010

Park, W. J., Schauder, K. B., Zhang, R., Bennetto, L., & Tadin, D. (2017). High internal noise and poor external noise filtering characterize perception in autism spectrum disorder. *Scientific Reports*. https://doi.org/10.1038/s41598-017-17676-5

Paton, B., Hohwy, J., & Enticott, P. G. (2012). The rubber hand illusion reveals proprioceptive and sensorimotor differences in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *42*(9), 1870–1883. https://doi.org/10.1007/s10803-011-1430-7

Peck, T. C., Seinfeld, S., Aglioti, S. M., & Slater, M. (2013). Putting yourself in the skin of a black avatar reduces implicit racial bias. *Consciousness and Cognition*, *22*(3), 779–787. https://doi.org/10.1016/j.concog.2013.04.016

Pellicano, E., & Burr, D. (2012). When the world becomes "too real": A Bayesian explanation of autistic perception. In *Trends in Cognitive Sciences*. https://doi.org/10.1016/j.tics.2012.08.009

Perez Repetto, L., Jasmin, E., Fombonne, E., Gisel, E., & Couture, M. (2017). Longitudinal Study of Sensory Features in Children with Autism Spectrum Disorder. *Autism Research and Treatment*, *2017*, 1–8. https://doi.org/10.1155/2017/1934701

Petersen, C. C. H., Hahn, T. T. G., Mehta, M., Grinvald, A., & Sakmann, B. (2003). Interaction of sensory responses with spontaneous depolarization in layer 2/3 barrel cortex. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.2235811100

Phillip, S. (2010). Integration of visual and proprioceptive information for reaching in multiple parietal areas. *Frontiers in Neuroscience*, *4*, 222–237. https://doi.org/10.3389/conf.fnins.2010.03.00093

Piek, J. P., & Dyck, M. J. (2004). Sensory-motor deficits in children with developmental coordination disorder, attention deficit hyperactivity disorder and autistic disorder. *Human Movement Science*. https://doi.org/10.1016/j.humov.2004.08.019

Piven, J., Palmer, P., Jacobi, D., Childress, D., & Arndt, S. (1997). Broader autism phenotype: Evidence from a family history study of multiple-incidence autism families. *American Journal of Psychiatry*, *154*(2), 185–190. https://doi.org/10.1176/ajp.154.2.185

Plaisted, K. (2015). Reduced Generalization in Autism: An Alternative to Weak Central Coherence.

Poole, L. B. (2015). The basics of thiols and cysteines in redox biology and chemistry. *Free Radical Biology and Medicine*, *80*, 148–157. https://doi.org/10.1016/j.freeradbiomed.2014.11.013

Posserud, M.-B., Lundervold, A. J., & Gillberg, C. (2006). Autistic features in a total population of 7-9-year-old children assessed by the ASSQ (Autism Spectrum Screening Questionnaire). *Journal of Child Psychology and Psychiatry*, *47*(2), 167–175. https://doi.org/10.1111/j.1469-7610.2005.01462.x

Powers, A. R., Hillock, A. R., & Wallace, M. T. (2009). Perceptual Training Narrows the Temporal Window of Multisensory Binding. *Journal of Neuroscience*, *29*(39), 12265–12274. https://doi.org/10.1523/JNEUROSCI.3501-09.2009

Powers, Albert R., Hillock-Dunn, A., & Wallace, M. T. (2016). Generalization of multisensory perceptual learning. *Scientific Reports*, *6*. https://doi.org/10.1038/srep23374

Preston, C. (2013). The role of distance from the body and distance from the real hand in ownership and disownership during the rubber hand illusion. *Acta Psychologica*, *142*(2), 177–183. https://doi.org/10.1016/j.actpsy.2012.12.005

Preston, C., & Newport, R. (2011). Analgesic effects of multisensory illusions in osteoarthritis. *Rheumatology*, *50*(12), 2314–2315. https://doi.org/10.1093/rheumatology/ker104

Price, K. J., Edgell, D., & Kerns, K. A. (2012). Timing deficits are implicated in motor dysfunction in Asperger's syndrome. *Research in Autism Spectrum Disorders*. https://doi.org/10.1016/j.rasd.2011.11.007

Price, K. J., Shiffrar, M., & Kerns, K. A. (2012). Movement perception and movement production in Asperger's Syndrome. *Research in Autism Spectrum Disorders*. https://doi.org/10.1016/j.rasd.2011.06.013

Proulx, T., Sleegers, W., & Tritt, S. M. (2017). The expectancy bias: Expectancy-violating faces evoke earlier pupillary dilation than neutral or negative faces. *Journal of Experimental Social Psychology*. https://doi.org/10.1016/j.jesp.2016.12.003

Raftery, A. E., Chunn, J. L., Gerland, P., & Ševčíková, H. (2013). Bayesian Probabilistic Projections of Life Expectancy for All Countries. *Demography*. https://doi.org/10.1007/s13524-012-0193-x

Rajendran, Gnanathusharan; Mitchell, P. (2014). Cognitive theories of autism. *Developmental Review*, *27*(2), 1–39. https://doi.org/10.1007/s13398-014-0173-7.2

Ramakonar, H., Franz, E. A., & Lind, C. R. P. (2011). The rubber hand illusion and its application to clinical neuroscience. *Journal of Clinical Neuroscience*, *18*(12), 1596–1601. https://doi.org/10.1016/j.jocn.2011.05.008

Ramakonar, H., Franz, E. A., & Lind, C. R. P. (2011). The rubber hand illusion and its application to clinical neuroscience. In *Journal of Clinical Neuroscience* (Vol. 18, Issue 12, pp. 1596–1601). https://doi.org/10.1016/j.jocn.2011.05.008

Ratcliffe, N., & Newport, R. (2017). The Effect of Visual, Spatial and Temporal Manipulations on Embodiment and Action. *Frontiers in Human Neuroscience*, *11*. https://doi.org/10.3389/fnhum.2017.00227

Regehr, G., MacRae, H., Reznick, R. K., & Szalay, D. (1998). Comparing the psychometric properties of checklists and global rating scales for assessing performance on an OSCE-format examination. *Academic Medicine*, *73*(9), 993–997. https://doi.org/10.1097/00001888-199809000-00020

Repacholi, B. M., Meltzoff, A. N., & Olsen, B. (2008). Infants' Understanding of the Link Between Visual Perception and Emotion: "If She Can't See Me Doing It, She Won't Get

Angry.” *Developmental Psychology*, *44*(2), 561–574. https://doi.org/10.1037/0012-1649.44.2.561

Rief, W., Glombiewski, J. A., Gollwitzer, M., Schubö, A., Schwarting, R., & Thorwart, A. (2015). Expectancies as core features of mental disorders. *Current Opinion in Psychiatry*, *28*(5), 378–385. https://doi.org/10.1097/yco.0000000000000184

Rincon-Gonzalez, L., Naufel, S. N., Santos, V. J., & Helms Tillery, S. (2012). Interactions Between Tactile and Proprioceptive Representations in Haptics. *Journal of Motor Behavior*, *44*(6), 391–401. https://doi.org/10.1080/00222895.2012.746281

Riquelme, I., Hatem, S. M., & Montoya, P. (2016). Abnormal Pressure Pain, Touch Sensitivity, Proprioception, and Manual Dexterity in Children with Autism Spectrum Disorders. *Neural Plasticity*, *2016*, 1–9. https://doi.org/10.1155/2016/1723401

Ro, T., Hsu, J., Yasar, N. E., Caitlin Elmore, L., & Beauchamp, M. S. (2009). Sound enhances touch perception. *Experimental Brain Research*, *195*(1), 135–143. https://doi.org/10.1007/s00221-009-1759-8

Robertson, A. E., & Simmons, D. R. (2012). The Relationship between Sensory Sensitivity and Autistic Traits in the General Population. *Journal of Autism and Developmental Disorders*, *43*(4), 775–784. https://doi.org/10.1007/s10803-012-1608-7

Robinson, E. B. (2011). Evidence That Autistic Traits Show the Same Etiology in the General Population and at the Quantitative Extremes (5%, 2.5%, and 1%). *Archives of General Psychiatry*, *68*(11), 1113. https://doi.org/10.1001/archgenpsychiatry.2011.119

Robledo, J., Donnellan, A. M., & Strandt-Conroy, K. (2012). An exploration of sensory and movement differences from the perspective of individuals with autism. *Frontiers in Integrative Neuroscience*. https://doi.org/10.3389/fnint.2012.00107

Rogers, S. J., & Ozonoff, S. (2005). Annotation: What do we know about sensory dysfunction in autism? A critical review of the empirical evidence. *Journal of Child Psychology and Psychiatry*, *46*(12), 1255–1268. https://doi.org/10.1111/j.1469-7610.2005.01431.x

Rogers, S. J., Hepburn, S., & Wehner, E. (2003). Parent Reports of Sensory Symptoms in Toddlers with Autism and Those with Other Developmental Disorders. *Journal of Autism and Developmental Disorders*, *33*(6), 631–642. https://doi.org/10.1023/B:JADD.0000006000.38991.a7

Ronald, A., & Hoekstra, R. A. (2011). Autism spectrum disorders and autistic traits: A decade of new twin studies. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics*, *156*(3), 255–274. https://doi.org/10.1002/ajmg.b.31159

Ronconi, L., Gori, S., Ruffino, M., Molteni, M., & Facoetti, A. (2013). Zoom-out attentional impairment in children with autism spectrum disorder. *Cortex*. https://doi.org/10.1016/j.cortex.2012.03.005

Ropar, D, & Mitchell, P. (2001). Susceptibility to illusions and performance on visuospatial tasks in individuals with autism. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *42*(4), 539–549. https://doi.org/10.1111/1469-7610.00748

Ropar, D., Greenfield, K., Smith, A. D., Carey, M., & Newport, R. (2018). Body representation difficulties in children and adolescents with autism may be due to delayed development of visuo-tactile temporal binding. *Developmental Cognitive Neuroscience*, *29*, 78–85. https://doi.org/10.1016/j.dcn.2017.04.007

Ropar, Danielle, & Mitchell, P. (1999). Are individuals with autism and Asperger's syndrome susceptible to visual illusions? *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *40*(8), 1283–1293. https://doi.org/10.1111/1469-7610.00544

Ropar, Danielle, & Mitchell, P. (2002). Shape constancy in autism: The role of prior knowledge and perspective cues. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *43*(5), 647–653. https://doi.org/10.1111/1469-7610.00053

Russo, N., Foxe, J. J., Brandwein, A. B., Altschuler, T., Gomes, H., & Molholm, S. (2010). Multisensory processing in children with autism: High-density electrical mapping of auditory-somatosensory integration. *Autism Research*, *3*(5), 253–267. https://doi.org/10.1002/aur.152

Ruzich, E., Allison, C., Smith, P., Watson, P., Auyeung, B., Ring, H., & Baron-Cohen, S. (2015a). Measuring autistic traits in the general population: a systematic review of the

Autism-Spectrum Quotient (AQ) in a nonclinical population sample of 6,900 typical adult males and females. *Molecular Autism*, *6*(1), 2. https://doi.org/10.1186/2040-2392-6-2

Ruzich, E., Allison, C., Smith, P., Watson, P., Auyeung, B., Ring, H., & Baron-Cohen, S. (2015b). Measuring autistic traits in the general population: A systematic review of the Autism-Spectrum Quotient (AQ) in a nonclinical population sample of 6,900 typical adult males and females. *Molecular Autism*. https://doi.org/10.1186/2040-2392-6-2

Salowitz, N. M. G., Eccarius, P., Karst, J., Carson, A., Schohl, K., Stevens, S., Van Hecke, A. V., & Scheidt, R. A. (2013). Brief report: Visuo-spatial guidance of movement during gesture imitation and mirror drawing in children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-012-1631-8

Sanchez-Marin, F. J., & Padilla-Medina, J. A. (2008). A psychophysical test of the visual pathway of children with autism. *Journal of Autism and Developmental Disorders*, *38*(7), 1270–1277. https://doi.org/10.1007/s10803-007-0507-9

Sarlegna, F. R., & Sainburg, R. L. (2009). The roles of vision and proprioception in the planning of reaching movements. *Advances in Experimental Medicine and Biology*, *629*, 317–335. https://doi.org/10.1007/978-0-387-77064-2_16

Schaaf, R. C., Benevides, T., Mailloux, Z., Faller, P., Hunt, J., Van Hooydonk, E., Freeman, R., Leiby, B., Sendecki, J., & Kelly, D. (2014). An intervention for sensory difficulties in children with autism: A randomized trial. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-013-1983-8

Schauder, K. B., Mash, L. E., Bryant, L. K., & Cascio, C. J. (2015). Interoceptive ability and body awareness in autism spectrum disorder. *Journal of Experimental Child Psychology*, *131*, 193–200. https://doi.org/10.1016/j.jecp.2014.11.002

Schauder, K. B., Mash, L. E., Bryant, L. K., & Cascio, C. J. (2015a). Interoceptive ability and body awareness in autism spectrum disorder. *Journal of Experimental Child Psychology*. https://doi.org/10.1016/j.jecp.2014.11.002

Schauder, K. B., Mash, L. E., Bryant, L. K., & Cascio, C. J. (2015b). Interoceptive ability and body awareness in autism spectrum disorder. *Journal of Experimental Child Psychology*, *131*, 193–200. https://doi.org/10.1016/j.jecp.2014.11.002

Schmitz, C., Martineau, J., Barthélémy, C., & Assaiante, C. (2003). Motor control and children with autism: Deficit of anticipatory function? *Neuroscience Letters*. https://doi.org/10.1016/S0304-3940(03)00644-X

Schneiberg, S., Sveistrup, H., McFadyen, B., McKinley, P., & Levin, M. F. (2002). The development of coordination for reach-to-grasp movements in children. *Experimental Brain Research*. https://doi.org/10.1007/s00221-002-1156-z

Schroeder, C. E., Wilson, D. A., Radman, T., Scharfman, H., & Lakatos, P. (2010). Dynamics of Active Sensing and perceptual selection. In *Current Opinion in Neurobiology* (Vol. 20, Issue 2, pp. 172–176). https://doi.org/10.1016/j.conb.2010.02.010

Schultz, R. T. (2005). Developmental deficits in social perception in autism: The role of the amygdala and fusiform face area. In *International Journal of Developmental Neuroscience* (Vol. 23, Issues 2-3 SPEC. ISS., pp. 125–141). https://doi.org/10.1016/j.ijdevneu.2004.12.012

Schütz-Bosbach, S., Mancini, B., Aglioti, S. M., & Haggard, P. (2006). Self and Other in the Human Motor System. *Current Biology*, *16*(18), 1830–1834. https://doi.org/10.1016/j.cub.2006.07.048

Seth, A. K., & Edelman, G. M. (2004). Environment and Behavior Influence the Complexity of Evolved Neural Networks. *Adaptive Behavior*, *12*(1), 5–20. https://doi.org/10.1177/105971230401200103

Shah, A., & Frith, U. (1983). AN ISLET OF ABILITY IN AUTISTIC CHILDREN: A RESEARCH NOTE. *Journal of Child Psychology and Psychiatry*, *24*(4), 613–620. https://doi.org/10.1111/j.1469-7610.1983.tb00137.x

Shams, L, Kamitani, Y., & Shimojo, S. (2000). What you see is what you hear. *Nature*, *408*(6814), 788. https://doi.org/10.1038/35048669

Shams, Ladan, Kamitani, Y., & Shimojo, S. (2002). Visual illusion induced by sound. *Cognitive Brain Research*, *14*(1), 147–152. https://doi.org/10.1016/S0926-

6410(02)00069-1

Sheppard, E., Ropar, D., & Mitchell, P. (2009). Perceiving the impossible: how individuals with autism copy paradoxical figures. *Autism : The International Journal of Research and Practice*, *13*(4), 435–452. https://doi.org/10.1177/1362361309105661

Shi, Z., & Müller, H. J. (2013). Multisensory perception and action: development, decision-making, and neural mechanisms. *Frontiers in Integrative Neuroscience*, *7*. https://doi.org/10.3389/fnint.2013.00081

Siaperas, P., Ring, H. A., McAllister, C. J., Henderson, S., Barnett, A., Watson, P., & Holland, A. J. (2012). Atypical movement performance and sensory integration in Asperger's syndrome. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-011-1301-2

Simmons, D. R., Robertson, A. E., McKay, L. S., Toal, E., McAleer, P., & Pollick, F. E. (2009). Vision in autism spectrum disorders. *Vision Research*, *49*(22), 2705–2739. https://doi.org/10.1016/j.visres.2009.08.005

Smith, E. G., & Bennetto, L. (2007). Audiovisual speech integration and lipreading in autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *48*(8), 813–821. https://doi.org/10.1111/j.1469-7610.2007.01766.x

Smith, R., Xia, G., Anderson, W., & Merkle, C. L. (2010). Smith-2010. *Interface*, *July*, 1–22.

Spence, C. (2010). Crossmodal spatial attention. In *Annals of the New York Academy of Sciences* (Vol. 1191, pp. 182–200). https://doi.org/10.1111/j.1749-6632.2010.05440.x

Spence, C., & Driver, J. (2012). Crossmodal Space and Crossmodal Attention. In *Crossmodal Space and Crossmodal Attention*. https://doi.org/10.1093/acprof:oso/9780198524861.001.0001

Steele, G. D., & Bramblett, C. A. (1988). *The Anatomy and Biology of the Human Skeleton* (1st ed.). Texas A&M University Press.

Stekelenburg, J. J., Maes, J. P., Van Gool, A. R., Sitskoorn, M., & Vroomen, J. (2013). Deficient multisensory integration in schizophrenia: An event-related potential study. *Schizophrenia Research*, *147*(2–3), 253–261.

https://doi.org/10.1016/j.schres.2013.04.038

Stenneken, P., Prinz, W., Bosbach, S., & Aschersleben, G. (2006). Visual proprioception in the timing of movements: Evidence from deafferentation. *NeuroReport*, *17*(5), 545–548. https://doi.org/10.1097/01.wnr.0000209013.01470.f8

Stevenson, R. A., Segers, M., Ferber, S., Barense, M. D., & Wallace, M. T. (2014). The impact of multisensory integration deficits on speech perception in children with autism spectrum disorders. *Frontiers in Psychology*, *5*(MAY). https://doi.org/10.3389/fpsyg.2014.00379

Stevenson, R. A., Segers, M., Ferber, S., Barense, M. D., Camarata, S., & Wallace, M. T. (2016). Keeping time in the brain: Autism spectrum disorder and audiovisual temporal processing. In *Autism Research* (Vol. 9, Issue 7, pp. 720–738). https://doi.org/10.1002/aur.1566

Stewart, M. E., & Ota, M. (2008). Lexical effects on speech perception in individuals with "autistic" traits. *Cognition*, *109*(1), 157–162. https://doi.org/10.1016/j.cognition.2008.07.010

Stewart, M. E., Watson, J., Allcock, A.-J., & Yaqoob, T. (2009). Autistic traits predict performance on the block design. *Autism*, *13*(2), 133–142. https://doi.org/10.1177/1362361308098515

Stroganova, T. A., Nygren, G., Tsetlin, M. M., Posikera, I. N., Gillberg, C., Elam, M., & Orekhova, E. V. (2007). Abnormal EEG lateralization in boys with autism. *Clinical Neurophysiology*, *118*(8), 1842–1854. https://doi.org/10.1016/j.clinph.2007.05.005

Summerfield, C., & Egner, T. (2009). Expectation (and attention) in visual cognition. *Trends in Cognitive Sciences*, *13*(9), 403–409. https://doi.org/10.1016/j.tics.2009.06.003

Sutherland, A., & Crewther, D. P. (2010). Magnocellular visual evoked potential delay with high autism spectrum quotient yields a neural mechanism for altered perception. *Brain*, *133*(7), 2089–2097. https://doi.org/10.1093/brain/awq122

Tager-Flusberg, H. (2008). Cognitive neuroscience of autism. *Journal of the International Neuropsychological Society*. https://doi.org/10.1017/S1355617708081423

Tang, G., Gudsnuk, K., Kuo, S.-H., Cotrina, M. L., Rosoklija, G., Sosunov, A., Sonders, M. S., Kanter, E., Castagna, C., Yamamoto, A., Yue, Z., Arancio, O., Peterson, B. S., Champagne, F., Dwork, A. J., Goldman, J., & Sulzer, D. (2014). Loss of mTOR-Dependent Macroautophagy Causes Autistic-like Synaptic Pruning Deficits. *Neuron*, *83*(5), 1131–1143. https://doi.org/10.1016/j.neuron.2014.07.040

Taylor, M. J., Rosenqvist, M. A., Larsson, H., Gillberg, C., D'Onofrio, B. M., Lichtenstein, P., & Lundström, S. (2020). Etiology of Autism Spectrum Disorders and Autistic Traits Over Time. *JAMA Psychiatry*, *77*(9), 936. https://doi.org/10.1001/jamapsychiatry.2020.0680

Thurm, A., & Swedo, S. E. (2012). The importance of autism research. *Dialogues in clinical neuroscience*, *14*(3), 219–222. https://doi.org/10.31887/DCNS.2012.14.3/athurm

Todorov, E., & Jordan, M. I. (2002). Optimal feedback control as a theory of motor coordination. *Nature Neuroscience*. https://doi.org/10.1038/nn963

Tomchek, S. D., Huebner, R. A., & Dunn, W. (2014). Patterns of sensory processing in children with an autism spectrum disorder. *Research in Autism Spectrum Disorders*, *8*(9), 1214–1224. https://doi.org/10.1016/j.rasd.2014.06.006

Touzalin-Chretien, P., Ehrler, S., & Dufour, A. (2010). Dominance of vision over proprioception on motor programming: Evidence from ERP. *Cerebral Cortex*, *20*(8), 2007–2016. https://doi.org/10.1093/cercor/bhp271

Tsakiris, M. (2010). My body in the brain: A neurocognitive model of body-ownership. *Neuropsychologia*, *48*(3), 703–712. https://doi.org/10.1016/j.neuropsychologia.2009.09.034

Tsakiris, M. (2011). The Sense of Body Ownership. In *The Oxford Handbook of the Self*. https://doi.org/10.1093/oxfordhb/9780199548019.003.0008

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: visuotactile integration and self-attribution. *J Exp Psychol Hum Percept Perform*, *31*(1), 80–91. https://doi.org/10.1037/0096-1523.31.1.80

Uljarevic, M., & Hamilton, A. (2012). Recognition of Emotions in Autism: A Formal Meta-Analysis. *Journal of Autism and Developmental Disorders*, *43*(7), 1517–1526. https://doi.org/10.1007/s10803-012-1695-5

Uljarevic, M., Prior, M. R., & Leekam, S. R. (2014). First evidence of sensory atypicality in mothers of children with Autism Spectrum Disorder (ASD). *Mol Autism*, *5*(1), 26. https://doi.org/10.1186/2040-2392-5-26

van Atteveldt, N., Murray, M. M., Thut, G., & Schroeder, C. E. (2014). Multisensory Integration: Flexible Use of General Operations. *Neuron*, *81*(6), 1240–1253. https://doi.org/10.1016/j.neuron.2014.02.044

Van Atteveldt, N., Murray, M. M., Thut, G., & Schroeder, C. E. (2014). Multisensory integration: Flexible use of general operations. In *Neuron* (Vol. 81, Issue 6, pp. 1240–1253). https://doi.org/10.1016/j.neuron.2014.02.044

Van Beers, R. J., Sittig, A. C., & Denier Van Der Gon, J. J. (1999). Integration of Proprioceptive and Visual Position-Information: An Experimentally Supported Model. *Journal of Neurophysiology*, *81*(3), 1355–1364. https://doi.org/10.1152/jn.1999.81.3.1355

Van Beers, R. J., Wolpert, D. M., & Haggard, P. (2002). When feeling is more important than seeing in sensorimotor adaptation. *Current Biology*, *12*(10), 834–837. https://doi.org/10.1016/S0960-9822(02)00836-9

Van de Cruys, S., Evers, K., Van der Hallen, R., Van Eylen, L., Boets, B., de-Wit, L., & Wagemans, J. (2014). Precise minds in uncertain worlds: Predictive coding in autism. *Psychological Review*, *121*(4), 649–675. https://doi.org/10.1037/a0037665

van der Smagt, M. J., van Engeland, H., & Kemner, C. (2007). Brief Report: Can You See What is Not There? Low-level Auditory–visual Integration in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *37*(10), 2014–2019. https://doi.org/10.1007/s10803-006-0346-0

Van Der Smagt, M. J., Van Engeland, H., & Kemner, C. (2007). Brief report: Can you see what is not there? Low-level auditory-visual integration in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *37*(10), 2014–2019.

https://doi.org/10.1007/s10803-006-0346-0

Vandenbroucke, M. W. G., Scholte, H. S., Van Engeland, H., Lamme, V. A. F., & Kemner, C. (2008). A neural substrate for atypical low-level visual processing in autism spectrum disorder. *Brain*, *131*(4), 1013–1024. https://doi.org/10.1093/brain/awm321

Vanegas, S. B., & Davidson, D. (2015). Investigating distinct and related contributions of Weak Central Coherence, Executive Dysfunction, and Systemizing theories to the cognitive profiles of children with Autism Spectrum Disorders and typically developing children. *Research in Autism Spectrum Disorders*, *11*, 77–92. https://doi.org/10.1016/j.rasd.2014.12.005

Vilidaite, G., Yu, M., & Baker, D. H. (2017). Internal noise estimates correlate with autistic traits. *Autism Research*, *10*(8), 1384–1391. https://doi.org/10.1002/aur.1781

Wallace, M. T., & Stevenson, R. A. (2014). The construct of the multisensory temporal binding window and its dysregulation in developmental disabilities. In *Neuropsychologia*. https://doi.org/10.1016/j.neuropsychologia.2014.08.005

Wallace, S., Coleman, M., Pascalis, O., & Bailey, A. (2006). A study of impaired judgment of eye-gaze direction and related face-processing deficits in autism spectrum disorders. *Perception*, *35*(12), 1651–1664. https://doi.org/10.1068/p5442

Wallwork, S. B., Bellan, V., Catley, M. J., & Moseley, G. L. (2016). Neural representations and the cortical body matrix: Implications for sports medicine and future directions. In *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2015-095356

Walter, E., Dassonville, P., & Bochsler, T. M. (2009). A specific autistic trait that modulates visuospatial illusion susceptibility. *Journal of Autism and Developmental Disorders*, *39*(2), 339–349. https://doi.org/10.1007/s10803-008-0630-2

Webb, S J, Neuhaus, E., & Faja, S. (2017). Face perception and learning in autism spectrum disorders. *Quarterly Journal of Experimental Psychology*, *70*(5), 970–986. https://doi.org/10.1080/17470218.2016.1151059

Webb, Sara Jane, Neuhaus, E., & Faja, S. (2016). Face Perception and Learning in Autism Spectrum Disorders. *The Quarterly Journal of Experimental Psychology*, *0218*(May), 1–44. https://doi.org/10.1080/17470218.2016.1151059

Webb, Sara Jane, Neuhaus, E., & Faja, S. (2017). Face perception and learning in autism spectrum disorders. *Quarterly Journal of Experimental Psychology*, *70*(5), 970–986. https://doi.org/10.1080/17470218.2016.1151059

Wechsler, D. (1981). The psychometric tradition: Developing the wechsler adult intelligence scale. *Contemporary Educational Psychology*, *6*(2), 82–85. https://doi.org/10.1016/0361-476x(81)90035-7

Weigelt, S, Koldewyn, K., & Kanwisher, N. (2011). Face identity recognition in autism spectrum disorders: A review of behavioral studies. *Neurosci Biobehav Rev*. https://doi.org/10.1016/j.neubiorev.2011.12.008

Weigelt, Sarah, Koldewyn, K., & Kanwisher, N. (2012). Face identity recognition in autism spectrum disorders: A review of behavioral studies. In *Neuroscience and Biobehavioral Reviews* (Vol. 36, Issue 3, pp. 1060–1084). https://doi.org/10.1016/j.neubiorev.2011.12.008

Weiss, S. J., Wilson, P., Hertenstein, M. J., & Campos, R. (2000). The tactile context of a mother's caregiving: implications for attachment of low birth weight infants☆. *Infant Behavior and Development*, *23*(1), 91–111. https://doi.org/10.1016/S0163-6383(00)00030-8

Weimer, A., Schatz, A., Lincoln, Y., Ballantyne, G., & Trauner, D. (2001). "Motor" Impairment in Asperger Syndrome: Evidence for a Deficit in Proprioception. *Journal of Developmental & Behavioral Pediatrics*, *22*(2), 92–101. https://doi.org/10.1097/00004703-200104000-00002

Whyatt, C. P., & Craig, C. M. (2012). Motor skills in children aged 7-10 years, diagnosed with autism spectrum disorder. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-011-1421-8

Whyatt, C., & Craig, C. (2013). Sensory-motor problems in autism. *Frontiers in Integrative Neuroscience*. https://doi.org/10.3389/fnint.2013.00051

Wiggins, L. D., Robins, D. L., Bakeman, R., & Adamson, L. B. (2009). Brief report: sensory abnormalities as distinguishing symptoms of autism spectrum disorders in young children. *Journal of Autism and Developmental Disorders*, *39*(7), 1087–1091.

https://doi.org/10.1007/s10803-009-0711-x

Wigham, S., Rodgers, J., South, M., McConachie, H., & Freeston, M. (2015). The Interplay Between Sensory Processing Abnormalities, Intolerance of Uncertainty, Anxiety and Restricted and Repetitive Behaviours in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-014-2248-x

Williams, J. H. G., Massaro, D. W., Peel, N. J., Bosseler, A., & Suddendorf, T. (2004). Visual-auditory integration during speech imitation in autism. *Research in Developmental Disabilities*, *25*(6), 559–575. https://doi.org/10.1016/j.ridd.2004.01.008

Windisch, S. I., Jung, R. E., Sailer, I., Studer, S. P., Ender, A., & Hämmerle, C. H. F. (2007). A new optical method to evaluate three-dimensional volume changes of alveolar contours: a methodological in vitro study. *Clinical Oral Implants Research*, *18*(5), 545–551. https://doi.org/10.1111/j.1600-0501.2007.01382.x

Wing, L., & Potter, D. (2002). The epidemiology of autistic spectrum disorders: Is the prevalence rising? In *Mental Retardation and Developmental Disabilities Research Reviews* (Vol. 8, Issue 3, pp. 151–161). https://doi.org/10.1002/mrdd.10029

Woloszyn. (2010). Contrasting Three Popular Explanations for the Muller-Lyer Illusion. *Current Research in Psychology*, *1*(2), 102–107. https://doi.org/10.3844/crpsp.2010.102.107

Woodbury-Smith, M. R., Robinson, J., Wheelwright, S., & Baron-Cohen, S. (2005). Screening Adults for Asperger Syndrome Using the AQ: A Preliminary Study of its Diagnostic Validity in Clinical Practice. *Journal of Autism and Developmental Disorders*, *35*(3), 331–335. https://doi.org/10.1007/s10803-005-3300-7

Woynaroski, T. G., Kwakye, L. D., Foss-Feig, J. H., Stevenson, R. A., Stone, W. L., & Wallace, M. T. (2013). Multisensory Speech Perception in Children with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *43*(12), 2891–2902. https://doi.org/10.1007/s10803-013-1836-5

Yaguchi, A., & Hidaka, S. (2018). Distinct Autistic Traits Are Differentially Associated With the Width of the Multisensory Temporal Binding Window. *Multisensory Research*, *31*(6), 523–536. https://doi.org/10.1163/22134808-00002612

Zhou, H., Cai, X.-, Weigl, M., Bang, P., Cheung, E. F. C., & Chan, R. C. K. (2018). Multisensory temporal binding window in autism spectrum disorders and schizophrenia spectrum disorders: A systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews*, *86*, 66–76. https://doi.org/10.1016/j.neubiorev.2017.12.013

Zwicker, J. G., Missiuna, C., Harris, S. R., & Boyd, L. A. (2012). Developmental coordination disorder: A review and update. In *European Journal of Paediatric Neurology*. https://doi.org/10.1016/j.ejpn.2012.05.005

Glossary

The terms and definitions provided below are in context of the research conducted. Please note that these definitions/ meanings are modified in the context of current research

Term	**Definition / Meanings**
ASD	Autism Spectrum Disorder
AQ	Autism Quotient
ASC	Autism Spectrum Conditions
ASD	Autism Spectrum Disorder
ADOS – II	Autism Diagnostic and observational scale second edition
AQ Scores	Autistic Quotient Scores
AQ Traits	Autistic Quotient Traits
Bottom- up information	processing the incoming sensory information, i.e. manipulation of the hand as viewed through the MIRAGE
Bayesian Integration	A theory of sensory integration that provides a systematic way of how the brain deals with a number of inputs, which vary in reliability. In doing so, it must create a coherent representation of the word that corresponds to reality.
CSC	congruent seen condition
CUS	congruent unseen condition
Cognitive style of thinking	This is a concept used in cognitive psychology to describe the way an individual think's- For example, people with autism have a

	detail oriented cognitive style- they focus on details that others overlook
DHT	Disappearing Hand Trick Illusion
EEG	Electroencephalogram
EQ	Empathizing Quotient
EHI	Edinburgh handedness inventory
EPC	Enhanced perceptual functioning theory
FMRI	Functional Magnetic resonance imaging
Global Processing	processing of information as wholes or the global percept, i.e. the visual manipulation seen as a part of the limb
HfA	High Functioning Autism
IQ	Intelligence Quotient
IUC	Incongruent Unseen Condition
Local Processing	processing of information through its local elements, i.e. disregarding the general aspect of the hand and rather focus on the individual aspects of the hand
Static hand/ crawling skin illusion	The crawling skin illusion has been named static hand. These terms are interchangeable but refer to the same thing- the experimental condition.
SPQ	Sensory Profiling Questionnaire
SPD	Sensory Processing Disorder
SQ	Systemizing Quotient
Top- down information	processing of information using contextual knowledge, i.e. prior knowledge about the hand

Lower-level sensory Processing	In sensory processing, this is the process that organizes sensations from one's own body and the environment- aiding in the effective use of the body within the environment
WAIS II	Wechsler abbreviated scale of intelligence second edition
High AQ scorers/ traits	Individuals of typical development with High autism scores
Low AQ scorers/traits	Individuals of typical development with Low autism scores
Higher – level processing	These processes involve an individual's contextual knowledge regarding events and things- such as prior knowledge regarding the shape and size of limbs
Internal sensory source	
External sensory source	
Proximal sensory source	
Distant sensory source	

Appendices

<u>Appendix 1</u>. Modified version of the Edinburgh handedness Inventory Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychololgia. This was presented online alongside the AQ using Qualtrics.

Initials:________________________________

Date of Birth:____________________________

Gender:__________________________

Handedness:_____________________________

Have you ever had any tendency toward left-handedness?

Yes ❑ No ❑

Please indicate your preferences in the use of hands in the following activities by putting ✓ in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ✓✓. If in any case you are really indifferent put ✓ in both columns (✓ | ✓).

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets. Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	Left Hand	Right Hand
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Comb		
6. Toothbrush		
7. Knife (without fork)		
8. Spoon		
9. Hammer		
10. Screwdriver		
11. Tennis Racket		
12. Knife (with fork)		
13. Cricket Bat (lower hand)		
14. Golf Club (lower hand)		
15. Using a Broom (upper hand)		
16. Rake (upper hand)		
17. Striking a Match (match)		
18. Opening box (lid)		
19. Dealing Cards (card being dealt)		

20. Threading needle (needle or thread according to which is moved)		

<u>Appendix 2.</u> The Autistic Quotient (AQ) (Baron-Cohen et al., 2001b)(The AQ was presented to the participants using an online Questionnaire software- Qualtrics). The order in which the statements were presented was randomized from the original AQ.

	Statements	**Definitely Agree**	**Slightly Agree**	**Slightly Disagree**	**Definitely Disagree**
1	I prefer to do things with others rather than on my own.				
2	I prefer to do things the same way over and over again.				
3	If I try to imagine something, I find it very easy to create a picture in my head				
4	I frequently get so strongly absorbed in one thing that I lose sight of other things.				
5	I often notice small sounds when others do not.				
6	I usually notice car number plates or similar strings of information.				
7	Other people frequently tell me that what I've said is impolite, even though I think it is polite.				
8	When I'm reading a story, I can easily imagine what the characters might look like.				
9	I am fascinated by dates.				
10	In a social group, I can easily keep track of several different people's conversations.				
11	I find social situations easy.				
12	I tend to notice details that others do not.				
13	I would rather go to a library than to a party.				
14	I find making up stories easy.				
15	I find myself drawn more strongly to people than to things.				

16	I tend to have very strong interests, which I get upset about if I can't pursue.				
17	I enjoy social chitchat.				
18	When I talk, it isn't always easy for others to get a word in edgewise.				
19	I am fascinated by numbers.				
20	When I'm reading a story, I find it difficult to work out the characters' intentions.				
21	I don't particularly enjoy reading fiction.				
22	I find it hard to make new friends.				
23	I notice patterns in things all the time.				
24	I would rather go to the theater than to a museum.				
25	It does not upset me if my daily routine is disturbed				
26	I frequently find that I don't know how to keep a conversation going.				
27	I find it easy to 'read between the lines' when someone is talking to me.				
28	I usually concentrate more on the whole picture, rather than on the small details.				
29	I am not very good at remembering phone numbers.				
30	I don't usually notice small changes in a situation or a person's appearance.				
31	I know how to tell if someone listening to me is getting bored.				
32	I find it easy to do more than one thing at once.				
33	When I talk on the phone, I'm not sure when it's my turn to speak.				
34	I enjoy doing things spontaneously.				
35	I am often the last to understand the point of a joke				
36	I find it easy to work out what someone is thinking or feeling just by looking at their face.				
37	If there is an interruption, I can switch back to what I was doing very quickly.				
38	I am good at social chitchat.				

39	People often tell me that I keep going on and on about the same thing				
40	When I was young, I used to enjoy playing games involving pretending with other children.				
41	I like to collect information about categories of things (e.g., types of cars, birds, trains, plants).				
42	I find it difficult to imagine what it would be like to be someone else				
43	I like to carefully plan any activities I participate in.				
44	I enjoy social occasions				
45	I find it difficult to work out people's intentions				
46	New situations make me anxious.				
47	I enjoy meeting new people.				
48	I am a good diplomat.				
49	I am not very good at remembering people's date of birth.				
50	I find it very easy to play games with children that involve pretending.				

Appendix 3. Subjective statements used during the MIRAGE investigations. These statements were obtained from investigations conducted using the MIRAGE previously (Newport et al., 2017, Bellan et al., 2015; McKenzie and Newport, 2015; Newport & Giplin, 2011).

Experiment	**Subjective statements**	**Category**
1 (chap 2)	The hand no longer feels like my hand (reverse scored) The hand belongs to me	**Ownership**
	I can feel a tingling sensation in my hand My hand feels like it has pins and needles I experience itching in my hand I feel like something is touching my hand I can feel an unpleasant sensation in my hand	**Somatosensory**
	I can hear something unusual when I look at my hand My hand feels like it is floating in air My hand feels heavier than normal	**Control**
2 (chap 3)	The hand no longer feels like my hand (reverse scored) The video hand belongs to me	**Ownership**
	I can feel a tingling sensation in my hand My hand feels like it has pins and needles	

	I experience itching in my hand I feel like something is touching my hand I can feel an unpleasant sensation in my hand	**Somatosensory**
	I can hear something unusual when I look at my hand My hand feels like it is floating in air My hand feels heavier than normal	**Control**
3 (Chap 4)	The finger that I see is a part of my body	**Ownership**
	It felt like my finger was really being stretched	**Illusion strength**
	My finger feels warmer than usual	**Control**
4 (Chap 5)	The finger that I see is a part of my body	**Ownership**
	It felt like my finger was really being stretched	**Illusion strength**
	My finger feels warmer than usual	**Control**
5 (chap 6)	The hands that I see are my own hands The hands that I see on the screen belongs to me The hands that I see on the screen are a part of my body	**Acclimatization**
6 (Chap 7)	The hands that I see are my own hands The hands that I see on the screen belongs to me The hands that I see on the screen are a part of my body	**Acclimatization**

Appendix 4a. Non- Somatosensory scores for the control condition- Chapter 2, Experiment 1

Non- Somatosensory Scores

Conditions	Groups	Mean (Std)
Veridical- baseline	High AQ Low AQ	1.81 (.506) 1.62 (.298)
Darkened	High AQ Low AQ	1.77 (.554) 1.61 (.382)
Crawling skin	High AQ Low AQ	1.76 (.533) 1.70 (.288)

Appendix 4b. Non- Somatosensory scores for control condition- chapter 3, Experiment 2

Non- Somatosensory Scores

Conditions	Groups	Mean (std)
Veridical- baseline	HfA Control	- 2.51 (.437) - 2.37 (.521)
Darkened	HfA Control	- 2.62 (.436) - 2.46 (.535)
Crawling skin	HfA Control	- 2.60 (.580) - 2.35 (.212)