Experience Dependent Sensorimotor Functioning in Adults with Severe Autism Spectrum Disorder

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Contents

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II Table Legends

III Figure Legends

IV Abbreviations

Abbreviation	Long Form
DSM-V	Diagnostic and Statistical Manual of Mental Disorders 5th Edition
IQ	Intelligence quotient
NICE	National Institute for Health and Care Excellence
fMRI	Functional magnetic resonance imaging
mPFC	Medial prefrontal cortex
STS	Superior temporal sulcus
IPL	Inferior parietal lobule
IFG	Inferior frontal gyrus
TMS	Transcranial magnetic stimulation
DSM-IV-TR	Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition Text Revision
BAGA	British Amateur Gymnastic Association
MABC(-2)	Movement Assessment Battery for Children Second edition
Verbal IQ / VIQ	Verbal intelligence quotient
PPVT(-4)	Peabody Picture Vocabulary test Fourth edition
SP(-2)	Sensory Profile Second edition
SRS(-2)	Social Responsiveness Scale Second edition
ADOS(-2)	Autism Diagnostic Observation Schedule
RT	Reaction time
MATLAB	Matrix laboratory
DV	Dependent variable
AI	Automatic imitation
AVI	Audio Video Interleave
ANOVA	Analysis of variance
PECS	Picture Exchange Communication System
RRBs	Restricted interests and repetitive behaviours
SCI	Social communication and interaction
ADHD	Attention deficit hyperactivity disorder
OCD	Obsessive–compulsive disorder
EEG	Electroencephalogram

V Publications and Presentations

Oulton, J. R., Causer, J., Bennett, S. J., Hollands, M., Bird, G., & Hayes, S. J. (2018). Autistic Adults Demonstrate Intact Sensorimotor Development. Poster presented at the 2018 Annual Meeting of the International Society for Autism Research, Rotterdam, Netherlands. Abstract retrieved from https://insar.confex.com/insar/2018/webprogram/start.html.

VI Thesis Abstract

The aim of this doctoral research was to provide new insights into sensorimotor development and functioning in autistic adults. First, classification measures (*Chapter Two*) were used to verify the diagnosis of autism, and automatic imitation (*Chapter Three*) was used to verify an intact perception-action link. In *Chapter Four*, in Twists, the trampolining group (those with sensorimotor experience) had a *First Fixation Location* on the incongruent model on the first trial but had a longer *First Fixation Duration* on the congruent model across the trials. Whereas the non-trampolining group (those without sensorimotor experience) did not attend to either model significantly differently in their *First Fixation Location* but had a longer *First Fixation Duration* on the incongruent model. In *Chapter Five*, for familiar actions, the *First Fixation Location* was on the autistic model on the first trial, and *First Fixation Duration* was longer on the autistic model across the trials. This indicates that the sensorimotor system in autistic individuals is attuned to autistic kinematics, due to attention being drawn to the autistic model and it being evaluated for longer. For the skilled actions across the trials, the *First Fixation Location* was on the typical model, and for the *Percentage of Total Fixation Duration* the typical model was fixated on for proportionately longer. This was then further investigated in *Chapter Six*, in which participants ability to pursue point-light displays performing trampolining actions was examined. Sensorimotor experience did not result in superior pursuit of the point-light displays; the trampolining and non-trampolining groups performed similarly with no significant differences in the number or duration of eye movements. Therefore, the result of sensorimotor experience is superior identification and initial evaluation seen in the first fixation but does not have a significant effect past this point. Taken together, it can be suggested that action observation is intact in moderate to severely autistic adults through experience dependent attentional differences. This will add to the literature and understanding of minimally verbal adults with moderate to severe autism, a vastly understudied population.

Chapter One: Introduction to Sensorimotor Control Processes in Autism Spectrum Disorder

Prologue

The current thesis contains four experimental chapters (*Chapters Three – Six*) examining the role of sensorimotor experience in autism spectrum disorder (henceforth autism) across automatic imitation, preferential viewing, and pursuit. Prior to these, an initial battery of measures (*Chapter Two*) investigated baseline differences between a group with sensorimotor experience of trampolining and a group without this experience. The findings in *Chapter Two* will inform the protocols of the proceeding chapters. The aim of this introductory chapter is to outline the chapters of this thesis and review the literature in which this thesis falls. This review will be presented within four thematic sections: (1) Autism Spectrum Disorder; (2) Perception in Autism; (3) Sensorimotor Development in Autism; (4) Action Observation. Here, there will be a discussion of the different theories, models, and definitions, though this is not intended to be an exhaustive review of all current literature within these themes. This will be summed up in the final sections with reference given to how these theories relate to the studies in this thesis. After this appraisal, individual chapter aims, and the methods used in each will be summarised to give a brief overview of the succeeding sections.

Autism Spectrum Disorder

The current criteria for a diagnosis of autism spectrum disorder, is defined in the Diagnostic and Statistical Manual of Mental Disorders 5th Edition (DSM-V) (American Psychiatric Association, 2013), as persistent deficits in social communication and interactions across multiple contexts, restricted and repetitive patterns of behaviour, which are not explained by intellectual disability or global developmental delay. Symptoms must cause clinically significant impairment in social, occupational, or other important areas of current functioning. Autism is classified into type and level of support needed (see Table 1); these classifications are split across two areas: social communication, and restricted and repetitive behaviours (Weitlauf, Gotham, Vehorn, & Warren, 2014). This inclusion of severity specifiers has been largely overlooked in previous criteria for a diagnosis of autism, even though it is an important indicator of social, occupational, and adaptive functioning (Constantino & Charman, 2016).

Table 1. *Criteria for determining symptom severity, adapted from American Psychiatric Association (2013). DSM-V, Development: Autistic disorder.*

Level	Definition
Level One: *Requires support*	Without support deficits in social communication impairments are noticeable with atypical or unsuccessful response to social overtures of others. May also have decreased interest in social interactions. Inflexibility of behaviour causes significant interference with functioning in one or more contexts.
Level Two: *Requires substantial support*	Marked deficits in verbal and non-verbal social communication skills that are apparent even with support. Limited initiation of social interaction and reduced or abnormal responses to social overtures from others. Inflexibility of behaviour means there is difficulty in coping with change or restricted and repetitive behaviours appear frequently and interferes with functioning in a variety of contexts.
Level Three: *Requires very substantial support*	Severe deficits in verbal and non-verbal social communication that causes severe impairments in functioning. Very limited initiation of social interactions and minimal response to social overtures from others. Inflexibility of behaviour means there is extreme difficulty coping with change or restricted and repetitive behaviours markedly interferes with all aspects of functioning.

Autism represents a spectrum, ranging in severity from severely challenged to extraordinarily gifted (Coulter, 2009). Generally, individuals requiring very substantial support are at the most severe end of the spectrum, often with learning difficulties and little or no language skills (Bölte et al., 2015; Falck-Ytter, Bölte, & Gredebäck, 2013; Riby & Hancock, 2008, 2009). Most autistic adults will require support in some aspect of their life, and therefore will be unable to live independently (Howlin, 2005). They are more likely to exhibit self-injurious behaviours, severe memory impairments, epilepsy, have a lack of non-verbal gestures, and avoidance of eye-contact (Dawson, 2008; Falck-Ytter et al., 2013; Klerk, Gliga, Charman, & Johnson, 2014). Some of these behaviours are thought to be due to coping with the demands of daily stressors or having no better means for communicating with others (Harms, Martin, & Wallace, 2010; Perrin, Anderson, & Van Cleave, 2014). This means that those with severe autism can be difficult to conduct research with, due to inflexibility of behaviour and extreme difficulty in coping with change. The result of this is that even though autism is a lifelong condition, there is relatively little research examining the severe end of the spectrum (Lecavalier, 2005), or adults requiring very substantial support (Shattuck et al., 2007). Therefore, little is known about the manifestations of the core deficits of autism into adulthood (Seltzer et al., 2003).

Autism is distinguished from other conditions by differences in social communication and reciprocal social behaviour which is accompanied by repetitive or stereotyped behaviours, making it difficult for typical individuals to communicate with autistic individuals (Constantino et al., 2003). These manifests can be impairing to some and crucially depends on factors outside the individuals who have these differences (Dinishak, 2016). Reciprocal social behaviours require the individual to know, interpret, and respond to the interpersonal cues of others and be motivated to do so to engage in social interactions (Aldridge, Gibbs, Schmidhofer, & Williams, 2012; Constantino et al., 2003). The social motivation hypothesis of autism suggests that autistic individuals do not have the same social drive as typical individuals, which means the same social skills are not developed in the same situation, and therefore an autistic person will not respond in the "expected" way (Bolis & Schilbach, 2018; Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012). For an autistic individual, the world is filled with social challenges and ambiguities, which mean atypical strategies are generally used in social situations such as attending to individual pieces of the face, i.e. the lips, rather than utilising the non-verbal communication that can come from other features such as the eyes. This means that autistic individuals can have difficulties in conceiving the meaning behind other people's behaviour (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Autistic individuals experience undesirable interaction, such as peer rejection, which produces greater levels of anxiety and decreased confidence, leading to a preference for isolation or minimal social contact (Bellini, 2004; Myles, 2003; Tantam, 2003; Tse, Strulovitch, Tagalakis, Meng, & Fombonne, 2007; White & Roberson-Nay, 2009).

Social difficulties are thought to be a core cognitive feature of autism, these difficulties in part may be due to a difficulty in theory of mind (Baron-Cohen, 2001; Jolliffe & Baron-Cohen, 2001). Theory of mind refers to the ability to infer mental states to an action, such as beliefs, desires, intentions, imagination, and emotions (Baron-Cohen, 2001). A difficulty with theory of mind can be expressed as an inability to distinguish between an individual having a mental experience (thinking about a dog) or a physical experience (holding a dog) (Baron-Cohen, 1996; Baron-Cohen & Cross, 1992; Baron-Cohen, Leslie, & Frith, 1985; Heavey, Phillips, Baron-Cohen, & Rutter, 2000). Theory of mind ability is examined with the Sally-Anne task, in which Anne can see into a box and Sally cannot, autistic individuals have trouble knowing whether Sally or Anne knows what the box contains (Baron-Cohen, 1996; Baron-Cohen & Cross, 1992; Baron-Cohen et al., 1985; Heavey et al., 2000). This inability can become a problem for an autistic individual when something happens which upsets someone else; the autistic individual will have difficulty putting the event together with the emotion (Baron-Cohen, 2000, 2001; Fletcher et al., 1995; Frith, 1989; Gallagher et al., 2000; Happé, 1997).

Approximately 50% of autistic individuals are also diagnosed with an intellectual disability (IQ below 70), and 70% meet the diagnostic criteria for a co-morbid physical or mental health problem (NICE Guidelines, 2014). This can include sleep disturbances, eating disorders, epilepsy, anxiety, depression, attention problems, motor coordination problems, dyspraxia, and sensory sensitivities (NICE Guidelines, 2014). Prevalence rates of autism have been steadily increasing over the last four decades. In 1978 it was thought that every 4 in 10,000 children would be diagnosed with autism (Rutter, 1978); in 2006 this had risen to approximately 1 in 100 (Baird et al., 2006). However, recent figures estimate the prevalence of autism to be at 1 in 64, with the ratio of known:unknown cases being 3:2 (Baron-Cohen et al., 2009). This is an estimated increase of 12 times from 1978, thought to be due to an uptake in early screening and intervention, and an increase in public awareness of the symptoms of autism (French & Kennedy, 2018; Kiss, Feldman, Sheldrick, & Carter, 2017). Children as young as 11 months can receive a diagnosis with the new toddler measures; previously, a child would not receive a formal diagnosis until age three or four years (Kiss et al., 2017; Lord, Luyster, Gotham, & Guthrie, 2012a). The rise in prevalence could also be due to the heritability rate of autism being at over 90% (Yang & Gill, 2007). Therefore, the need for exploring all aspects of this condition has intensified with prevalence in order to get a comprehensive overview of the different ways in which autism can manifest. A greater understanding of what differences there are in autism and what shortcomings there are in society (i.e. understanding, making more places autism friendly), can then be used to improve the lives of people with autism (Renty & Roeyers, 2006) and solve societal problems, such as the unemployment rates in autism (Kapp, Gillespie-Lynch, Sherman, & Hutman, 2013; Mavranezouli et al., 2014; Renty & Roeyers, 2006).

Perception in Autism

Autism is considered to have a unique cognitive and perceptual style which is detail-orientated (Happé & Frith, 2006). Autistic individuals have trouble integrating component features or ideas, into global, coherent wholes, which results in an enhanced ability to process smaller details (Blake, Turner, Smoski, Pozdol, & Stone, 2003; Dillen, Steyaert, De Beeck, & Boets, 2015). Which means autistic individuals tend to process local information (the smaller details) over global information (the bigger picture), meaning autistic individuals perceive the world differently compared to typical individuals who process the global information (Bolis & Schilbach, 2018; Hill, 2004). This superior attention to detail (weak central coherence) makes autistic individuals better performers in low-level visual tasks and illusions (Whyatt & Craig, 2013), such as the embedded figures test (Happé, 1997). Children with autism outperform typical adults on the adult embedded figures test (Schlooz & Hulstijn, 2014) in which a smaller target shape is embedded in a larger figure, where the aim is to detect the smaller target shape. In typical individuals, the larger global figure interferes with detecting the smaller local target shape, but this effect is not seen in autistic individuals and therefore they excel (Dillen et al., 2015). In the same vein, autistic individuals have superior detection of modified melodies over typical individuals; they can recognise the identical, transposed melodies (when only the local features differed), but were not able to process the contour of a melody (Mottron, Peretz, & Menard, 2000). This evidence suggests that global features could not be processed because the autistic individuals were focussing on the notes of the melody (the local features) rather than the rising and falling of the pitch directions. This superiority in attention to detail does not just apply to laboratory tests. In the original description of autism, Kanner (1943) described this crossover into to other areas of life as the

> *'inability to experience wholes without full attention to the constituent parts as one factor in the characteristic insistence on sameness: a situation, a performance, a sentence is not regarded as complete if it is not made up of exactly the same elements that were present at the time the child was first confronted with it. If the slightest ingredient is altered or removed, the total situation is no longer the same and therefore is not accepted as such'* (Kanner, 1943, p.246).

This extract gives insight into the maladaptive side of this superior attention to detail; in that distress can be caused by small changes in the environment (Happé & Frith, 2006). This describes the inflexibility caused by this attention to detail, but also suggests that autistic individuals have a difference in information-processing (Jolliffe & Baron-Cohen, 1999). It has been suggested from this that autism should not be conceptualised as a disability, but rather a different type of information-processing (Jolliffe & Baron-Cohen, 1997, 1999, 2001).

Cognitive superiorities found in autism are thought to be explained by the systemising theory (Baron-Cohen, Knickmeyer, & Belmonte, 2005). Systemising is the drive to understand objects and events by their structure, which can be used to predict future events and behaviours. Systems are universal and appear in different forms in the environment, technical systems (machines), abstract systems (computers or maths), and natural systems (geographic or biological) (Baron-Cohen, 2006). An example of a biological structure is biological motion, which is a biological entity performing a recognisable activity, of which the biological action can be recognised from representations of what the body is capable of (Jeannerod, 2004a, 2004b; Jeannerod & Pacherie, 2004; Pelphrey & Morris, 2006; Wilson & Knoblich, 2005). This representation then influences visual perception of what is and is not biological motion

(Jeannerod, 2004a). A functional magnetic resonance imaging (fMRI) study showed activation of motor areas when observing finger, hand, arm, mouth, and foot movements, but not when the movement was biologically impossible (an arm rotating past its possible range) (Stevens, Fonlupt, Shiffrar, & Decety, 2000). Motion of a biological entity is necessary for the identification of a stimuli as biological; four-legged animals or birds can be recognised from statics of point-light displays (sparse input stimuli), but a human cannot be recognised from a static because the movement is necessary (Pavlova, Krägeloh-Mann, Sokolov, & Birbaumer, 2001).

There is an overlap in the neural networks used for biological motion and visual social cognition (superior temporal sulcus and inferior frontal gyrus), so it would be expected for autistic individuals to have difficulties in perceiving biological motion (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009; Sokolov et al., 2012). How an action is performed can differ based on social and emotional context, for example, reaching for a pen to sign one's name can infer such. If the signature is made with a flourish compared to a shaky reluctance, emotional state can be inferred from the kinematic features of the movement (Krishnan-Barman, Forbes, & Hamilton, 2017). This can be investigated using a preferential viewing protocol in which two stimuli are shown on screen at the same time. Klin et al. (2009) found that autistic participants made a greater number of saccades than the typical participants, and more saccades off screen, when an upright point-light display was shown alongside an inverted point-light display, indicating a difference in attention to each point-light display. The mouth region of the face is generally preferred in autistic individuals more than in typical individuals, however, both autistic and typical participants prefer upright point-light displays (Falck-Ytter, 2015; Jones, Carr, & Klin, 2008; Klin et al., 2002; Klin et al., 2009). Typical participants tend to prefer social over non-social in a preferential viewing protocol, and autistic participants prefer non-social, this is because typical participants have enhanced visual discrimination of point-light displays on social stimuli and therefore this type of stimuli is easier to process (Falck-Ytter et al., 2013). Autistic individuals do not show this enhancement, even though there are no differences in attention or recognition of the point-light displays in autistic participants (Riby & Hancock, 2008, 2009; Von Der Lühe et al., 2016).

Imitation

The kinematics of an action influences the way in which it is imitated, when shown videos of a hand pointing with fast or slow velocities, and goal or not goal directed, participants more accurately imitate velocity of an action when is not goal directed (Wild, Poliakoff, Jerrison, & Gowen, 2010). However, when there is a goal, the end point of the action is the focus of the participant's movement (Wild et al., 2010). The goal-directed theory of imitation (Bekkering, Wohlschlager, & Gattis, 2000), suggests that individuals engage in top-down cognitive processes during imitation to develop a hierarchy of goals related to the observed movement, the goal hierarchy could include the end-point of an action, the purpose of the action (i.e. what the action achieves), and the means of achieving the goal (movement of the limbs), which are ranked according to how the observer interacted with the model and environment (Hayes, Andrew, Elliott, Gowen, & Bennett, 2016a; Wild, Poliakoff, Jerrison, & Gowen, 2012). When a horizontal movement occurs with an atypical kinematic profile (reaching peak velocity much earlier than normal and therefore would not be part of the participant's existing sensorimotor repertoire), typical peak velocity is reached at 50% of the movement time, so early being at 17% or 26% of the movement time, Hayes, Dutoy, Elliott, Gowen, and Bennett (2016b) found that only typical participants were able to accurate imitate the atypical velocity profile, though the autistic participants reproduced the movement time. The presence of a goal in this protocol influences the accuracy of imitation, giving shorter movement times, even though the kinematic profile of the movement was the same (Hayes et al., 2016b). Similarly, Wild et al. (2012) found that autistic participants did not imitate the velocity of observed actions, whether it is goal directed or not. Therefore, autistic individuals may not track action kinematics in the same way as typical individuals, suggesting that there are aspects of movement that are sensitive to the presence of a goal (Krishnan-Barman et al., 2017). In everyday life, actions take place in a social context, generally with goals, therefore it is important to understand the influence of kinematics in motor control and social cognition (Wolpert, Doya, & Kawato, 2003). Social factors associated with the model being imitated modulate the action-observation network due to the processing of biological motion (Wang & Hamilton, 2012), in the social top-down response model (STORM; Wang & Hamilton, 2012), the medial prefrontal cortex (mPFC) and the temporo-parietal junction (TPJ) regulates the processing of biological motion in the superior temporal sulcus (STS) (Forbes, Wang, & Hamilton, 2017; Hamilton, 2013), suggesting that there is a link between action observation and mentalising networks within the brain (discussed later in Action Observation). To imitate, information derived from action observation is used in the mentalising systems to simulate the movements to aid imitation, therefore in the latter chapters because a point-light display will be used, the social nature of the models is controlled and recognition of the models should not be effected by the social features of movements but from the sensorimotor experience the participants have in their sensorimotor repertoire.

There are two routes in which an observed action can be imitated: a semantic route, using the goal of the action to comprehend the meaning, and a direct route to imitate meaningless movements without a goal (Vivanti & Hamilton, 2014). Together, these routes make up a visual-motor processing stream, in which the observed action (visual input) is translated into an action (motor output) (Cisek & Kalaska, 2010). Here, action production and prediction are closely linked, associations with prediction modulate production and vice versa

(Heyes, 2011; Prinz, 1990). The associative sequence learning theory of imitation proposes that matching associations between the observed movement, activates each connecting sensory and motor representations from similar actions within the sensorimotor repertoire, acquired through sensorimotor experience (Catmur, Walsh, & Heyes, 2009; Gillmeister, Catmur, Liepelt, Brass, & Heyes, 2008). This has been investigated in a finger lifting paradigm, in which participants make an index or middle finger movement in response to a number one or two appearing, respectively (Brass, Bekkering, Wohlschläger, & Prinz, 2000). During this task, the participant observes a task-relevant or -irrelevant stimulus, which matches the movement they have to make (compatible) or does not match and instead demonstrates the other movement (incompatible). Observing the compatible stimulus results in faster reaction times (automatic imitation effect) (Brass et al., 2000), suggesting that the perception-action link can be advantageous to performance. Automatic imitation is mediated by the same processes as motor mimicry, which is spontaneous and unconscious, occurring in a natural social setting (Cook, Bird, Lünser, Huck, & Heyes, 2011; Cook, Dickinson, & Heyes, 2012b; Heyes, 2011). For example, a participant is likely to engage in foot-shaking when in the presence of a foot-shaking confederate (Chartrand & Bargh, 1999).

Models of imitation (Gonzalez Rothi, Ochipa, & Heilman, 1991; Tessari, Canessa, Ukmar, & Rumiati, 2007) tend to have three phases. The first being the encoding phase, in which a representation is formed based on the properties of the action the observer's attention is drawn to (Vivanti & Rogers, 2011). The next phase (cross-modal / transformation / matching phase) involves the observer matching the formed representation of the observed action to previously learned action, in terms of the motor aspects and the semantic value of the action. If the representation does not match a known action, the action is deemed as novel, and the action can be imitated purely based on the perceptual motor features, with no semantic mediation (Vivanti & Rogers, 2011). The final stage is the execution phase, in which the action is imitated. In the last phase, if the representation matched, the previously learnt semantic and motor aspects of the action mediates the execution of the action. This mediation includes more efficient motor planning (compared to if the action is not learnt), which begins when observing the action (Vivanti & Rogers, 2011). However, this process can be interfered with; an interference effect is seen if the observed action competes with an action that is being executed. For example, viewing a horizontal movement while performing a sinusoidal vertical movement creates more variance in the horizontal dimension of the executed movement than when viewing a vertical movement (Kilner, Paulignan, & Blakemore, 2003).

Neural mechanisms of imitation include a cascade of cortical areas, the occipital cortex maps the observed action, and the formed representation is projected to the superior temporal sulcus (STS), an area involved in high level visual processing. The STS has been found to be selectively activated when observing biological movements (Grezes & Decety, 2001; Pelphrey & Morris, 2006; Stevens et al., 2000). From this, it has been suggested that the STS is specialised in interpreting social gestures and movements, such as joint attention (gaze and head movements), and in processing information conveyed in biological motion (Pelphrey, Morris, & McCarthy, 2005). The STS then projects to the inferior parietal lobule (IPL), which is activated during action observation and execution (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996). Action observation is thought to mediate the process of understanding the action (in the matching phase described previously) (Fogassi & Luppino, 2005). The inferior parietal lobule then projects to the inferior frontal gyrus (IFG; Broca's area) and the premotor area. These areas contain neurons associated with action observation which activate both during observation and execution of actions (similar to the IPL) (Vivanti & Rogers, 2011). The difference between the activation in the IFG and the IPL, is that the IFG activates when observing and executing non-identical actions that are associated with the same goal. Which indicates a semantic value to the representation of the observed action, which then mediates the visuomotor mapping in the observer's representation (Blaesi & Wilson, 2010; Dapretto et al., 2006; Iacoboni & Mazziotta, 2007; Rizzolatti & Craighero, 2004; Tessari et al., 2007). The final projection is from the IFG back to the STS, where efferent motor plans originate, which includes a visual description of the observed action, and the predicted sensory and motor consequences. This is an ongoing process to determine if the goal of the action has been achieved (Catmur, Walsh, & Heyes, 2007; Catmur et al., 2009; Iacoboni & Mazziotta, 2007; Rizzolatti & Craighero, 2004).

The neural pathway model described above identifies that both the visual and motor systems are used to process and understand actions that are observed. It is not just the basic visuospatial properties of the action that are used to imitate an action, but our own motor repertoire that is used to map the action into a motor representation (Grezes & Decety, 2001; Iacoboni, 2009; Iacoboni & Mazziotta, 2007; Stevens et al., 2000; Vivanti & Rogers, 2011). Observing the action elicits the encoding of the kinematics of the action and prompts the retrieval of motor representations which are associated with achieving the same goal, which means imitation is flexible; semantic or visuospatial coding can be continually used to process an action into a representation so that imitation can seem to flow seamlessly (Vivanti & Hamilton, 2014; Vivanti & Rogers, 2011).

Sensorimotor Development

Sensory and motor differences are not considered core criterium of autism, but they are highly prevalent (Gowen & Hamilton, 2013). Motor coordination difficulties effect the capability to recognise emotions in others (Cummins, Piek, & Dyck, 2005), the ability to attribute mental states to others, and therefore predict behaviours (Baron-Cohen, 2001, 2005; Baron-Cohen & Belmonte, 2005; Baron-Cohen et al., 1985; Vivanti & Rogers, 2011). These differences can significantly impact social development, through difficulties in coordination, accuracy, speed, and initiation of eye movements; therefore impacting the ability to integrate visual information into motor learning (Cleaver, Hunter, & Ouellette-Kuntz, 2009; Mostofsky, Goldberg, Landa, & Denckla, 2000; Ruigrok et al., 2014). Responsivity to sensory input and integration of the information plays a key role in the core symptoms of autism (Jones et al., 2008; Klin, Jones, Schultz, & Volkmar, 2003; Klin et al., 2002), which could account for social communication difficulties (Hannant, Tavassoli, & Cassidy, 2016b). Since the first descriptions of autism by Kanner (1943) and Asperger (1944), motor anticipation problems have been featured, including postural abnormalities, bradykinesia, hyperkinesia, and abnormality of muscle tone (rigidity and hypotonia), effecting the ability to successfully react to the environment and therefore the ability to communicate (Dowell, Mahone, & Mostofsky, 2009; Matson, Matson, & Beighley, 2011; Setoh, Marschik, Einspieler, & Esposito, 2017; Torres, 2013; Vernazza-Martin et al., 2005; Zachor, Ilanit, & Itzchak, 2010).

Sensory feedback and movement are intrinsically connected; the ability to plan and execute a movement requires sensory feedback (Brooks, 1983). Sensory feedback from the visual and proprioceptive systems provide a sense of how the task is progressing (Gowen & Hamilton, 2013). For example, when reaching for a cup you use information about where your hand is in relation to the position to the cup, and where the cup is in the environment. Using this information, the motor system can be used to plan the movement so that it is smooth and efficient, after this the motor system can then be used to move the hand towards the cup (Gowen & Hamilton, 2013; Hannant, Cassidy, Tavassoli, & Mann, 2016a). If the sensory and motor systems are used in a unified and continuous way, any errors, such as missing the cup resulting from a planning error can be processed and corrected (Hannant et al., 2016a). If continuous sensory feedback is automatic, consequences of the action can be predicted as the motor command is generated and corrected accordingly (Gowen & Hamilton, 2013; Todorov &

Jordan, 2002; Wolpert, Diedrichsen, & Flanagan, 2011; Wolpert & Flanagan, 2001). If there is a mismatch between predicted and sensory information, the sensorimotor system uses reactive control mechanisms alongside the predictive, referred to as sensorimotor learning: improvement through practice of sensory-guided motor behaviour (Krakauer & Mazzoni, 2011). For example, lifting a ceramic mug up compared to a plastic mug, the knowledge of this action will be updated to take the weight into account for next time. This sensorimotor learning makes new mappings between sensory and motor modalities, numerous factors can change these mappings, such as change in weight of an object or muscle fatigue; successful performance requires adaption to these factors (Wolpert et al., 2011).

Responsivity in the sensory modalities (auditory, visual, touch, and oral) differs in autistic individuals, with sensory and multisensory processing affected, leading to problems with sensorimotor learning (Kern et al., 2007b). The degree to which participants use proprioceptive or visual feedback during the formation of mappings for actions was measured using a robot arm; in training a cursor on a computer screen moved perpendicular to the direction that the participants move the robot arm (Mostofsky & Ewen, 2011). Participants were told to move the cursor towards a target; the cursor either moved perpendicularly (as in the initial training, which measured a visual link) or the opposite way (which measured a proprioceptive link) (Mostofsky & Ewen, 2011). Autistic participants used proprioceptive information more than visual information; due to the association of the proprioceptive feedback with the motor commands being stronger in autistic individuals than typical individuals (Mostofsky & Ewen, 2011). This could explain social difficulties in autism: if the association between visual feedback is weaker, less information will be taken in from the social interaction in autistic individuals (Hannant et al., 2016b).

Those with autism have difficulty integrating sensory information in motor learning; there is increased intrinsic asynchrony between visual and motor systems, increasing with autism severity (Nebel et al., 2016). This process is referred to as sensorimotor integration, a process which allows for the connection between sensory and motor systems (Machado et al., 2010). Difficulties in sensorimotor integration are exhibited as problems in using sensory feedback to correct movements, resulting in errors in coordination problems and difficulties responding to sensory input (Hannant et al., 2016b). Moreover, children with autism who have decreased intrinsic visual-motor synchrony are worse imitators than those with greater synchrony, which means this asynchrony contributes towards a difficulty in acquiring crucial social and communicative skills (Nebel et al., 2016).

Social problems in autism may be due to predictive difficulties, events may occur unexpectedly and without cause due to problems with processing and representing such stimuli. This can be overwhelming and compromise the ability to effectively interact, and therefore attention is not drawn to such stimuli which increases with severity (Dapretto et al., 2006; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Sinha et al., 2014). This supports the broken mirror theory (Ramachandran & Oberman, 2006), which claims impaired social skills in autism are related to an inability to simulate behaviour, making it difficult to understand the behaviour of others (Catmur et al., 2007; Cook, Bird, Catmur, Press, & Heyes, 2014b; Ramachandran & Oberman, 2006). Simulation is thought to be an important process in imitation (Oberman & Ramachandran, 2007); if there is a difficulty here this would impact social and motor development (Fan, Decety, Yang, Liu, & Cheng, 2010; Hamilton, 2013).

Gowen and Hamilton (2013) proposed that autistic individuals have a unique sensory input, together with a variability in motor execution. Autistic individuals have difficulty achieving the goal of an action, as orientating towards the goal in motor planning is challenging. Vernazza-Martin et al. (2005) found that 78% of autistic participants did not reach the goal of a motor action; due to significant differences between autistic and typical participants in gait, segmental orientation, and balance strategies. This difficulty in motor planning and changing an already learned movement is a problem with sensorimotor integration, as the ability to execute a learned movement is intact in autism (Nazarali, Glazebrook, & Elliott, 2009; Rinehart et al., 2006).

Problems with sensorimotor integration have been linked to the cerebellum, which contains pathways that link sensory signals to motor areas, which is important for sensorimotor integration, and in controlling and coordinating movement (Hannant et al., 2016b), with difficulties in error-reducing functions being shown in saccadic accuracy (Gepner & Mestre, 2002; Schmitt, Cook, Sweeney, & Mosconi, 2014). The cerebellum is also responsible for triggering learned movement, and therefore is intrinsic to predicting movement outcomes (Brooks, 1983; Fuentes & Bastian, 2007; Mostofsky et al., 2000). Structural differences in the size of the grey and subcortical white matter in cerebellum is thought to have impact on sensorimotor development in autistic individuals (Martineau, Andersson, Barthélémy, Cottier, & Destrieux, 2010; McAlonan et al., 2002; Mosconi, Wang, Schmitt, Tsai, & Sweeney, 2015). There is also less prefrontal activation during visuomotor learning in autistic individuals, enhanced activation in the right pericentral and in the premotor cortex compared with typical controls (Müller, Cauich, Rubio, Mizuno, & Courchesne, 2004). This is an area associated with action observation, which is supposedly suppressed in autistic individuals (Cross & Iacoboni, 2014; Oberman et al., 2005; Ramachandran & Oberman, 2006).

Action Observation

Initially, action observation was studied in macaque monkeys, the system is activated when performing an action as well as observing another performing a similar act (Gallese et al., 1996; Gentilucci et al., 1988; Rizzolatti et al., 1988). When observing a known action, there is activation in the motor areas associated with performing the action, which becomes stronger with experience of the action (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006). Actions that we have no prior experience of do not produce a similar activation, because observers use representations in their motor system as a mechanism to understand, predict, and learn (Centelles, Assaiante, Etchegoyhen, Bouvard, & Schmitz, 2013; Centelles, Assaiante, Nazarian, Anton, & Schmitz, 2011; Fan et al., 2010; Hamilton, 2013; Kirsch & Cross, 2015). A known, meaningful action is matched to a representation, for example, observing a person brush their teeth, or pretend to brush their teeth, activates the representation of teeth brushing, which includes the motor knowledge of how to execute it (Vivanti & Hamilton, 2014).

Sensorimotor behaviours can be learnt from observing other's motor actions; this involves integrating sensory and motor behaviour into a representation (Elliott, Wing, & Welchman, 2010; Wolpert et al., 2011). As James (1890) put it, 'The images of feelings we get from our own body, and the representations of our own movements distinguish themselves from all others' (pg. 303). It has been theorised that action observation serves a social function, with six month old infants showing activation to social stimuli, indicating humans can almost immediately respond to their environment (Saffin & Tohid, 2016; Simpson, Murray, Paukner, & Ferrari, 2014). With two different networks that this can happen in: the action observation and the mentalising networks (Pokorny, Hatt, Rogers, & Rivera, 2018). The mentalising network consists of the medial prefrontal cortex, posterior superior temporal sulcus, temporoparietal junction, and precuneus (Frith & Frith, 2006). This network is also used for theory of mind, which could be used to understand why the action is being performed from the perspective of the performer (Gallagher & Frith, 2003; Pokorny et al., 2018). Whereas the action observation network consists of the lateral dorsal and ventral premotor cortex, inferior frontal gyrus, the inferior and superior parietal lobules, intraparietal cortex, the postcentral gyrus, and the superior and middle temporal gyri (Pokorny et al., 2018). This network is used during action observation, observing, executing, and understanding an action, as well as simulating similar motor representations to predict the immediate outcome of the action (Pokorny et al., 2018). Note that there is little crossover between the mentalising and action observation networks, but there is crossover between action observation and the areas used during imitation (premotor cortex, IFG, and IPL, see previous section on Imitation). Compared with typical controls, there is less activation in the mentalising network in autism, but similar activation in the action observation network (Castelli, Frith, Happé, & Frith, 2002; Kana, Keller, Cherkassky, Minshew, & Just, 2009). Conventional actions use both networks, whereas unconventional actions only use the action observation, due to unclear goals in the unconventional actions intentions cannot be extrapolated using the mentalising network (Pokorny et al., 2018). However, through the IFG, context for the action can be established in the action observation network through sensorimotor representations from within the individual's sensorimotor repertoire (Blaesi & Wilson, 2010; Dapretto et al., 2006; Iacoboni & Mazziotta, 2007; Rizzolatti & Craighero, 2004; Tessari et al., 2007). There were no differences between autistic children and typical controls in functional magnetic resonance imaging (fMRI) study when observing conventional eating actions, with activation in the action observation network and the STS indicating no neural impairments or global differences in all aspects of action observation in autism (Pokorny et al., 2018). Therefore, action observation is intact in autism, even if mentalising is not (Castelli et al., 2002; Kana et al., 2009).

For action prediction, there does not need to be contextual information to predict the outcome of an action, for example, participants can judge the end location for an object being thrown from watching a point-light display of the movement (Zhu & Bingham, 2014). Even complex predictions can be made in the absence of context: a participant can anticipate whether an object is grasped with the intention of cooperating, competing, or performing an individual action (Ansuini, Cavallo, Bertone, & Becchio, 2015; Becchio, Manera, Sartori, Cavallo, &

Castiello, 2012; Manera, Becchio, Schouten, Bara, & Verfaillie, 2011). Predictions and predictive gaze during action observation depend on the activation of corresponding representations in the motor system (Elsner, D'ausilio, Gredebäck, Falck-Ytter, & Fadiga, 2013). Using transcranial magnetic stimulation (TMS) to stimulate the hand motor area (Elsner et al., 2013), and also when participants hands are tied behind their back (Ambrosini, Sinigaglia, & Costantini, 2012), predictive eye movements are disrupted when observing point-light displays of hand movements (Ambrosini et al., 2012; Elsner et al., 2013). This interrupts the prediction during action observation, because the observed movement must be mapped onto the motor representation (Blaesi & Wilson, 2010; Dapretto et al., 2006; Iacoboni & Mazziotta, 2007; Rizzolatti & Craighero, 2004; Tessari et al., 2007).

The representation of an action corresponds to the neural processes that need to take place beforehand, the motor aspects of the action, and also the consequence of the action (Grezes & Decety, 2001; Stevens et al., 2000). This occurs in the last stage of processing, which includes intention, preparation (involving the motor representation), and expression (Grezes & Decety, 2001). This is because action observation and action execution have overlapping brain areas, observing a movement activates the premotor cortex in a somatotopic manner, as well as the area that is used when executing it (Buccino et al., 2001). However, only biological movements are processed in this way. Non-biological movements, such as watching a ball bounce, does not produce the same activation or interference effects, due to having more experience of human kinematics as human movements are observed and experienced in everyday life (Kilner, Hamilton, & Blakemore, 2007; Kilner et al., 2003; Neal & Kilner, 2010). Therefore, the action observation system is more likely to respond to such, as it is within our motor repertoire (Ding et al., 2015; Kilner et al., 2007).

Sensory input that is associated with an action produces a similar activation to observing a known action (Herwig, Prinz, & Waszak, 2007). When pianists, experts (Haueisen & Knösche, 2001), and beginners (Bangert & Altenmüller, 2003), listen to known and experienced melodies, they produce activation in the motor areas that are associated with playing the piano. The representations associated with the observed movement can be used to infer other's intentions as well as anticipate the effects of an action (Mostofsky & Ewen, 2011; Prinz, 1997; Von Der Lühe et al., 2016; Wilson & Knoblich, 2005). For example, basketball athletes predict the success of shots quicker and more accurately than novices, based on the kinematics of the movement (Aglioti, Cesari, Romani, & Urgesi, 2008). Whether the action has been experienced visually or physically has the potential to shape how the action is perceived; participants learnt actions while blindfolded (purely motor) have greater sensitivity to the learned movements than when learnt purely visually (Calvo-Merino et al., 2006; Casile & Giese, 2005; Kirsch & Cross, 2015). Perception is therefore influenced by motor experience and visual experience, for example by observing other's movements and our own movements.

Early visual experiences play an important role in regulating the visuomotor system; our own kinematics have a significant impact on the sensitivity to the kinematics of others (Cook, Blakemore, & Press, 2013; Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005). Motor difficulties in autism at a gross and fine level, could underlie a difference in the sensorimotor system (Gowen & Hamilton, 2013; Gowen & Poliakoff, 2012). Which means autistic individuals may develop different representations to typical individuals, with representations attuned to motor differences that do not accord with typical kinematics (Cook et al., 2013; Sangrigoli et al., 2005). The greater the difference in kinematics in autistic individuals, the greater the bias toward perceiving biological motion as unnatural (Cook et al., 2013; Cook, Swapp, Pan, Bianchi-Berthouze, & Blakemore, 2014a). These atypical sensorimotor behaviours can severely impact the day-to-day well-being of autistic individuals

(Dawson, 2008; Vivanti & Hamilton, 2014; Vivanti, Hocking, Fanning, & Dissanayake, 2017; Vivanti et al., 2018).

Summary of Research and Current Thesis

The aim of the above introductory sections was to provide an overview of the literature on sensorimotor development in autism, including differences in the sensorimotor system, perceptual differences, imitation, and action observation. In doing this, it is clear that there are differences in the way the sensory and motor systems develop in autism when compared with the typical population (Baranek, 2002; Kaur, Srinivasan, & Bhat, 2018; Matson et al., 2011; Shafer, Newell, Lewis, & Bodfish, 2017; Torres, 2013). Motor differences when compared to typical controls have been widely reported, and could lead to sensorimotor integration differences (Forti et al., 2011; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Gowen & Hamilton, 2013; Springer et al., 2011; Travers, Powell, Klinger, & Klinger, 2013). These differences impact the way in which the sensory and motor systems interact, which can influence covert behaviours such as social (Cleaver et al., 2009; Lombardo & Baron-Cohen, 2010), imitation (Catmur et al., 2009; Cook, Press, Dickinson, & Heyes, 2010), and sensorimotor learning (Blandin, Lhuisset, & Proteau, 1999; Macinska, Krol, & Jellema, 2015; Müller et al., 2004). This could mean that alongside the perceptual differences that have already been discussed, the way the sensorimotor system has developed and adapted due to experience could influence the perception of these actions and how that individual reacts (Cook et al., 2013; Cusack, Williams, & Neri, 2015; Elsner & Hommel, 2001; Kirsch & Cross, 2015; Sangrigoli et al., 2005). Differences in sensorimotor integration and kinematics has led to the conclusion that autistic individuals have a specific kinematic profile, of which their sensorimotor system is attuned to their atypical kinematics, which differs from a typical individual's (Cook, 2016; Cook et al., 2013; Mostofsky & Ewen, 2011). This difference in kinematics may lead to a difference in perception, due to differences in the development of internal action models (Cook, 2016; Cook et al., 2013).

However, to date, studies examining sensorimotor functioning in adults with severe autism are few (Seltzer et al., 2003; Shattuck et al., 2007). The majority of studies focus on young toddlers or more able adults; as these individuals are easier to evaluate using standard assessment tools validated in the typical population, and are more compliant during tasks (Tager-Flusberg & Kasari, 2013). However, this is not representative of the autistic population, as between 30-50% of children with autism fail to acquire spoken language, of which is needed for the majority of tasks for adults (Anderson et al., 2007; National Research Council, 2001; Tager-Flusberg, Paul, & Lord, 2005). In consideration of the identified gap in the literature, it is necessary and meaningful to conduct research with autistic individuals who are minimally verbal. Most of the literature mentioned above was conducted with typical adults, autistic children, or autistic adults who would be classified as requiring level one support (mild autism, see Table 1). Research into sensorimotor development and functioning in severe and minimally verbal autistic adults was deemed as vital to build an understanding of these mechanisms in this population (Shafer et al., 2017). Due to advances in technologies that allow less-invasive measures to be taken, such as eye movements, it is now possible to explore differences in sensorimotor functioning in moderate to severely autistic adults (Panchuk, Vine, & Vickers, 2015).

The inclusion of older minimally verbal individuals will increase the true heterogeneity of the population in the literature (Tager-Flusberg et al., 2017). *The overall aim* of the present thesis was to examine if the sensorimotor system is functional in autistic adults, to do this *the main question* of the present thesis was to investigate whether having sensorimotor experience of a movement influences how an autistic individual perceives an observed point-light model that is performing experienced movements. This will be examined in four experimental chapters (*Chapter Three, Four, Five, Six*), which use behavioural methods to compare the difference sensorimotor experience has on perception. As illustrated in Figure 1, Sensorimotor Development and Functionality in Autism will be examined, to do this in *Chapter Two* measurement techniques for social and motor competencies will be quantified in minimally verbal autistic adults. A battery of verbal, social, sensory, and motor proficiency will be used in *Chapter Two* to determine how protocols should be designed and what the level of understanding and severity of participants is. In Figure 1, *Chapter Two* is joined through a dashed line because it does not directly relate to examining Sensorimotor Development and Functionality in Autism. The chapters that do relate are indicated via solid lines. These include *Chapter Three*, in which automatic imitation will be examined to investigate whether the perception-action link in moderate to severe autistic adults is intact. This is important for *Chapter Four, Five,* and *Six* in which the effect of sensorimotor experience on perception is examined. In *Chapters Four* and *Six*, this sensorimotor experience is of trampolining actions, as well as this in *Chapter Five* the sensorimotor experience is of the autistic model compared to a typical model is examined. *Chapters Three* to *Six* relate to how the action observation system functions, and therefore if perception differs as a function of sensorimotor experience and development. In the following subsections, specific hypotheses will be presented in relation to each individual chapter.

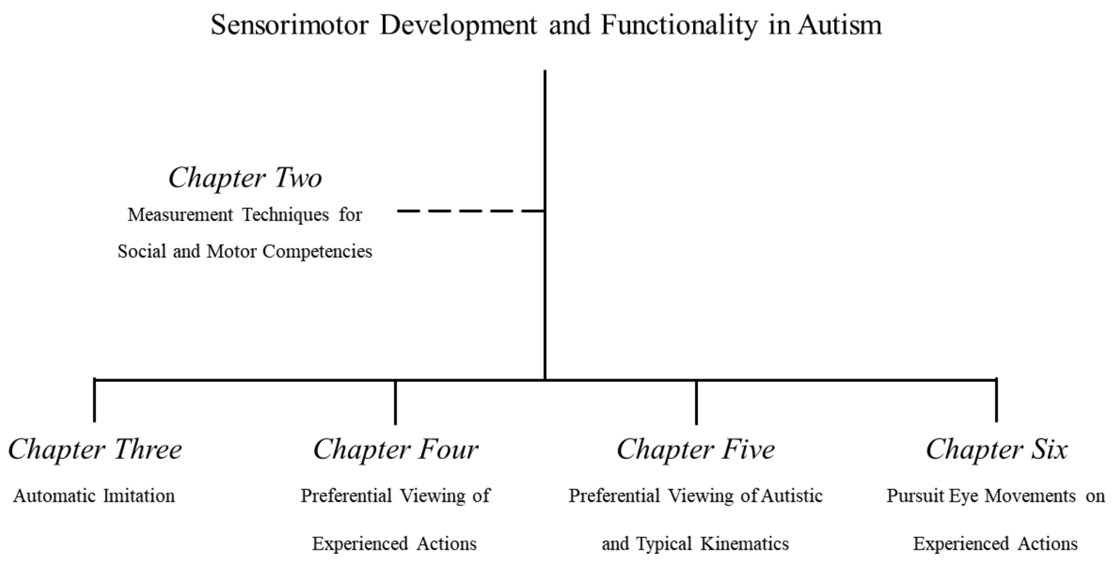

Figure 1. Overview of experimental chapters.

Chapter Two

In *Chapter Two*, the aim is to use various measurement techniques to provide quantifiable demographic scores for the participants, to aid clarity of the volunteers, to support cross-study comparison, and to facilitate the methods being replicated. To do this, measures of verbal intelligence, social responsiveness, sensory processing patterns, and motor proficiency will be used (Constantino & Gruber, 2012; Dunn & Dunn, 2007; Dunn, 2014; Henderson, Sugden, & Barnett, 2007). Based on the findings, subsequent studies will be adapted to make them more accessible to these participants, as well as giving an indication to the cognitive ability, and verbal understanding of the participants.

Chapter Three

In *Chapter Three*, the aim is to examine whether there is an automatic imitation effect present in adults with moderate to severe autism. Previous research (Bird, Leighton, Press, &

Heyes, 2007; Sowden, Koehne, Catmur, Dziobek, & Bird, 2016) suggests that there will be an automatic imitation effect observed in autistic adults, based on studies with participants who have who would be classified as requiring level one support (mild autism). However, it is not known how more severely autistic individuals imitate, and if there will be an automatic imitation effect, due to this population being understudied in this area (Seltzer et al., 2003; Shattuck et al., 2007). If an automatic imitation effect is found in moderate to severely autistic adults, this will indicate an intact perception-action link.

Chapter Four

In *Chapter Four*, the aim is to examine if sensorimotor experience of trampolining would influence the perception of a point-light display performing the experienced movements in moderate to severe autistic adults. A preferential viewing protocol will be used, in which point-light displays will perform trampolining actions or gait. On one side of the screen a model will be upright (congruent) and on the otherside the model was simultaneously performing the same action, but will be inverted (incongruent). Previous research suggests that there will be gaze behaviour differences between the group with experience of the actions and the group without this experience, due to intact sensorimotor functioning in autistic adults (Hayes et al., 2018). Due to the invasive techinques generally used in examining action observation (fMRI, EEG, TMS, EMG), and these techniques not being appropriate for severely autistic participants because of the associated self-injurious behaviours and restricted and repetitive behaviours (Dawson, 2008; Falck-Ytter, 2015; Falck-Ytter et al., 2013; Riby & Hancock, 2009), there is relatively little research investigating sensorimotor development and functionality at the severe end of the spectrum. Therefore, this research is needed to add to the literature and understanding of these individuals, and how their sensorimotor system adapts following sensorimotor experience.

Chapter Five

In *Chapter Five*, the aim is to examine whether moderate to severe autistic adults are preferentially drawn to autistic or typical kinematics. The same protocol will be used in this chapter as in *Chapter Four*, except in this preferential viewing protocol the models will be both upright, one model will be autistic and the other will be typical. Previous research suggests that the autistic adults will have an attraction to the autistic model because this model will resonate more in their motor system than the typical model (Cook et al., 2013; Foster et al., 2018; Shafer et al., 2017; Torres, 2013). However, it is not known whether the action observation/mirror system in autism is broken (Deschrijver, Wiersema, & Brass, 2017a; Martineau et al., 2010; Oberman & Ramachandran, 2007; Ramachandran & Oberman, 2006), or attuned to autistic kinematics in severely autistic adults (Cook, 2016; Cook et al., 2013; Rinehart et al., 2006). This study aims to fill this gap in the literature, to expand the knowledge on how the action observation system in autism responds to autism kinematics and typical kinematics, attraction to one model over another indicates motor specificity, whereas no attraction indicates the models are treated as the same (independent of resonance) and could be support for a broken system.

Chapter Six

In *Chapter Six*, the aim is to examine whether moderate to severe autistic adults with sensorimotor experience of trampolining can pursue trampolining actions better than those without experience. Participants will observe a point-light display of a autistic model performing Straight Jumps and Seatdrops, of which only the trampolining group will have sensorimotor experience of. It is suggested that autistic individuals have oculomotor difficulties that result in poor pursuit performance, but there is some equivocality within the literature (Aitkin, Santos, & Kowler, 2013; Johnson, Lum, Rinehart, & Fielding, 2016; Takarae, Luna, Minshew, & Sweeney, 2008; Takarae, Minshew, Luna, Krisky, & Sweeney, 2004a; Takarae, Minshew, Luna, & Sweeney, 2007). This could stem from the use of non-biological motion stimuli and/or differences in experience of the observed movement (von Lassberg, Beykirch, Campos, & Krug, 2012). Therefore, there are no predictions for this chapter on whether sensorimotor experience will result in superior pursuit performance or if oculomotor problems will overshadow any advantage having experience of the actions will give. Due to there being little consensus in the literature and therefore little prediction about how participants with and without experience will pursue a point-light display, this means that this research will enhance our understanding of oculomotor movements, predictive eye movements, and the use of sensorimotor representations in pursuit in severely autistic adults.

Chapter Seven

In *Chapter Seven*, the aim is to summarise the findings of this programme of work, and to critically analyse them with reference to the literature on imitation, action observation, and sensorimotor development. The findings will then be compared against theoretical models and accounts of impairments, deficits, and difficulties that are reported in the autism literature. These discussions will then inform possible future directions that could be investigated following the results of this programme of work, with the possibility in the future of using this research as the basis for sensorimotor rehabilitation to improve sensorimotor functioning in autistic individuals.

Summary of Thesis Aims and Objectives

The main aims across the chapters is to invesitgate sensorimotor functioning in autistic adults, to do this, in *Chapters Two* and *Three* participants will undergo several measurement techniques to measure the severity of autism (*Verbal IQ, Social Responsiveness Scale, Sensory Profile,* and *Movement Assessment Battery for Children*) and also a stimulus-response compatibility paradigm (Automatic Imitation) to evaluate the perception-action link in the autistic adults. After this, in *Chapters Four, Five,* and *Six,* gaze behaviour will be compared between two groups and two models, one group with sensorimotor experience of the actions and one group without this sensorimotor experience. If there are differences between the groups (in *Chapters Four* and *Six*) and perception of the models in *Chapter Five*, then it can be inferred that action obervation is intact in autistic adults through differences in gaze behaviour as a function of sensorimotor experience.

Chapter Two: Measurement Techniques for Social and Motor Competencies

Abstract

The aim of this chapter is to use various measurement techniques to provide quantifiable demographic scores for the participants, to aid clarity of the volunteers, to support cross-study comparison, and to facilitate the methods being replicated. Participants were split into two groups depending on if they have sensorimotor experience of trampolining or not. Both groups of participants performed below standardised averages on *Verbal IQ* and for motor ability, 54% of participants scored the baseline for verbal understanding and vocabulary, and 69% had scores within the significant motor difficulty category for motor ability. *Social Responsiveness* indicated severity of participants to be moderate to severe, and *Sensory Profile* indicated participants have more avoiding behaviours than in typical populations, particularly in auditory and touch symptoms, and attentional behaviours. Findings from *Verbal IQ, Sensory Profile, and Social Responsiveness* indicate that there may be some difficulty with understanding task requirements, as well as restricted and repetitive behaviours affecting the completion of some tasks. Therefore, some of the protocols in later chapters will need to be modified to be inclusive to those at the most severe end of the autistic spectrum. No significant differences in the gross motor ability was reported between the two groups, which is important for the subsequent studies of the current thesis examining experience dependent perceptual differences. Therefore, subsequent conclusions from perceptual differences can be drawn with the knowledge that motor execution (and therefore identification using motor representations) should also not be significantly different between the groups.

Introduction

Autism is a condition that can manifest in different ways depending upon the individual (Dinishak, 2016). There is not one set of autistic characteristics that present in all that are diagnosed, however, there are traits which are common and used as diagnostic criteria (Haythorne & Seymour, 2016). Autism is generally characterised by difficulties in social interaction and communication, as well as restricted interests and repetitive behaviours (American Psychiatric Association, 2013; Weitlauf et al., 2014). However, how a child presents during development may also not apply or match the expression of autism shown as an adolescent or adult (Esbensen, Greenberg, Seltzer, & Aman, 2009a; Esbensen, Seltzer, Lam, & Bodfish, 2009b; Fecteau, Mottron, Berthiaume, & Burack, 2003).

Sensory Processing Patterns

Autism is associated with a range of non-social features, such as hyper- and hypo-sensitivities to perceptual stimuli, enhanced sensation, and sensory overload, leading to sensory seeking behaviours such as attraction to light, fascination with bright colours, or avoidance of such (Chambon et al., 2017; Turi, Muratori, Tinelli, Morrone, & Burr, 2017). Sensory processing refers to the way the cerebral cortex and brainstem manage sensory information (visual, auditory, vestibular, proprioceptive), and the adaptive responses to these stimuli (Baker, Lane, Angley, & Young, 2008). These behaviours are typically categorised into the auditory, visual, and tactile senses. Auditory hyposensitivity can include diminished response when their name is being called, hypersensitivity includes aversions to certain sounds because they are too loud and painful (Tomchek & Dunn, 2007). Visual hyposensitivity can include avoidance of eye contact, with hypersensitivity being inspecting objects in an unusual way, such as with peripheral vision (Tomchek & Dunn, 2007). Finally, tactile hypersensitivity can include becoming anxious due to certain clothing fabrics, and tactile hyposensitivity being a lowered pain threshold (Symons, 2011; Tomchek & Dunn, 2007). It has been suggested that hyposensitivities are due to diminished top-down prior expectations of perceptual experience, with a consequence of enhanced bottom-up functioning, manifesting as an increased reliance on sensory information (Lawson, Rees, & Friston, 2014; Van de Cruys et al., 2014). Sensory processing patterns can be investigated through the *Sensory Profile* (Dunn, 2014). The *Sensory Profile* categorises sensory processing into the senses: auditory, visual, touch, movement, body position, and oral (Dunn, 2014). Sensory processing pattern differences have been found in as many as 94.44% of autistic adults, with an extreme level of sensory processing in at least one distinct domain of the *Sensory Profile* (Crane, Goddard, & Pring, 2009; Dunn, 2014). Previously, it was thought that this level of extreme sensory processing would dissipate with age (Kern et al., 2007b). However, this has no bearing on the population of severely autistic adults, for those who are consistently classified as severe throughout their diagnoses. Generally, research does not focus on severely autistic adults and so little is known about how the condition manifests through life in those who are severely autistic (Dinishak, 2016; Shattuck et al., 2007).

Social Responsiveness

Although sensory processing is not included in the criteria for a diagnosis of autism, sensory processing and social difficulties can limit an individual's ability to fully engage in everyday life (Hilton, Graver, & LaVesser, 2007; Myles, 2003). The impact of this can be seen in reduced eye contract, increased looking at the mouth, body, and object areas indicate social difficulties (Jones et al., 2008). Social difficulties are thought to cause social anxiety in autistic individuals, with a strong correlation between *Social Responsiveness* factors and autism symptoms (Bellini, 2004; Chan, Smith, Hong, Greenberg, & Mailick, 2017; Hilton et al., 2007).

Social communication and restricted and repetitive behaviours are the two core symptoms of the levels of support criteria (American Psychiatric Association, 2013; Weitlauf et al., 2014). *Social Responsiveness* refers to the ability to engage in emotionally appropriate reciprocal social interactions, and influences the degree to which an autistic adult can function independently (Constantino et al., 2003; Mostofsky & Ewen, 2011). Social skills are learnt by performing actions and interpreting the resulting sensory feedback, with an understanding of other's movements and the intentions associated (Klin et al., 2003). Action models fit this description, so it follows that if there are difficulties in using these mechanisms to learn motor skills, as is known in autism (see *Chapter One*), then there will be difficulties in the formation of action models for social skills (Mostofsky & Ewen, 2011).

Motor Proficiency

Difficulties in performing motor skills prevents children and adolescents with autism from engaging in social interactions during active play time in school and in their leisure time (MacDonald, Lord, & Ulrich, 2013). This can negatively impact upon social skills and can further reduce the activity levels; which could lead to individuals being less likely to adopt active lifestyles as adults (Cummins et al., 2005). An active lifestyle and exercising has many health benefits, including a short-term reduction in stereotypic behaviours, aggression, and off-task behaviours in children with autism (Lang et al., 2010; Petrus et al., 2008). Behaviours commonly linked to autism can also be limiting factors in getting autistic adults physically active, such as sensitivity to light and sounds in fitness clubs, difficulties in social interactions (particularly with team sports and group activities), and gross motor difficulties (making certain sports challenging) (Buchanan, Miedema, & Frey, 2017; Eaves & Ho, 2008; Nichols, Block, Bishop, & McIntire, 2019).

Motor difficulties are associated with autism, with problems in motor preparation, which leads to movement errors and longer initiation of movement (Papadopoulos et al., 2012; Rinehart et al., 2006; Stoit, van Schie, Slaats-Willemse, & Buitelaar, 2013). This association has been used as a method of classifying children into high- and low-functioning using upper limb ability, which is 96.7% accurate (Crippa et al., 2015). However, motor ability does not differ between participants with autism and typical controls when motor preparation is made easier, i.e. when participants are told where to expect a target to appear (Glazebrook, Elliott, & Szatmari, 2008). Gross motor skills in children with autism are below what would be typically expected for their chronological age, with postural stability influencing the ability to perform these gross motor movements (Mache & Todd, 2016). Adaptive behaviours and daily living skills are impacted by poor motor skills, as accidents are caused from movement errors and control, reducing their independence and quality of life (MacDonald et al., 2013; Miller, Chukoskie, Zinni, Townsend, & Trauner, 2014).

Verbal Intelligence and Intellectual Disabilities

Nevertheless, autism severity is not a predictor of poor motor ability or poor motor skills (Mache & Todd, 2016). Lower scores on tests of motor skill are associated with intellectual disability, which is thought to effect a large percentage of autistic individuals, with a correlation between IQ and motor ability, and IQ and variability in postural sway (Charman et al., 2011; Kaur et al., 2018; Staples & Reid, 2010; Travers, Mason, Gruben, Dean, & McLaughlin, 2018; Westendorp, Houwen, Hartman, & Visscher, 2011). Although autistic individuals without intellectual disabilities also exhibit fundamental motor skill difficulties, it follows that these difficulties are not solely associated with IQ but related to a neurological difference (Mache & Todd, 2016).

IQ and language level are closely linked with overall functioning, therefore, knowing an individual's IQ and functional language ability can serve as a proxy for how debilitating their condition is (Lord & Bishop, 2015; Weitlauf et al., 2014). Collection of IQ data in the autism community poses a challenge, with vast heterogeneity between those with a superior cognitive ability and those with profound intellectual disability; there is difficulty in finding a measure that is inclusive for all (Krasileva, Sanders, & Bal, 2017). A brief assessment, such as the Peabody Picture Vocabulary Test (Dunn & Dunn, 2007) can be administered quickly and does not necessitate spoken language, which is especially useful in a severe population who are predominantly minimally verbal. There are age norms for 2-90 year olds, that encompass the wide range of abilities, for different ages and cognitive abilities (Krasileva et al., 2017). Therefore, the Peabody test can be inclusive to a population that is highly heterogenous, especially at the severe end of the autistic spectrum, which is an important aspect of the current thesis, given the paucity of research for severely autistic adults and the difficulties in data collection with these individuals. Any difficulties found in verbal intelligence, social responsiveness, motor ability, or differences in sensory processing patterns, can be examined and quantified in the current study, which can then be used to appropriately design further studies so that they are inclusive and suitable to the participant's needs, with flexible arrangements that can work around participants.

Autism as a Condition

The DSM-V (American Psychiatric Association, 2013) criteria for autism spectrum disorder is a list of deficits, impairments, limitations, negatively valued deviations from behavioural norms (e.g. diminished contact, difficulties in social interactions such as responding or failure to initiate), and repetitive or stereotyped activities (e.g. body rocking, flapping, echolalia) (Dinishak, 2016). There is a focus on distinct clinical categories rather than categorical decisions focussing on the individual's strengths and weaknesses, which largely ignores autistic strengths (Robertson, 2009). The current criteria referring to autism as a disorder is stigmatising, autism or autism spectrum condition is preferable; this recognises that there are both strengths and weaknesses associated, while still being a clinical condition for which some individuals need support (Hannant et al., 2016b).

In addition, the diagnostic criteria for autism has recently changed in the DSM-V from the DSM-IV-TR (American Psychiatric Association, 2000, 2013); Asperger's disorder, childhood disintegrative disorder, and pervasive developmental disorder not otherwise specified, are now included in the diagnosis of autism spectrum disorder (American Psychiatric Association, 2000, 2013). Respectively, a recent meta-analysis found autistic individuals are likely to receive a similar diagnosis using the DSM-IV-TR or the DSM-V criteria, with only 63% of people with a DSM-IV-TR diagnosis of autism meeting the new diagnostic criteria for autism (Bennett & Goodall, 2016). However, during an observation, the variation in functioning across environmental context and demands cannot be measured, therefore accounts from caregivers are needed to assess how symptomology changes dependent on time, condition, and context. Therefore, aspects of the individuals life that could not be ascertained through exam or observation can be reported and considered when making a diagnosis, aspects such as peer relationships, social communication, and rigidity of repetitive patterns of behaviour (Constantino & Charman, 2016). Therefore, measures such as the *Sensory Profile* (Dunn, 2014) and the *Social Responsiveness Scale* (Constantino & Gruber, 2012) can make for a more holistic approach to classifying someone as autistic, which is a more reliable method when considering all aspects of an individual's life (Aldridge et al., 2012; Tomchek & Dunn, 2007).

Researchers have suggested that autistic-like traits extend into the general population, with a continuum distribution from those who meet the diagnostic criteria to those who do not

(Baron-Cohen, 2001; Constantino & Charman, 2016; Happé & Frith, 2006). From a research perspective, tests of autistic symptoms tend to use a system of categories to classify, this means that there has to be a clear distinction in between categories that are by nature dimensional and continuous (Happé & Frith, 2006). Therefore, due to variability and heterogeneity in the expression of autistic traits, the cut-off scores designed for making this distinction seem somewhat arbitrary in nature (Constantino & Charman, 2016). The variability in behaviour is particularly seen at the severe end of the spectrum, which is now thought to make up approximately 50% of the autism population (Underwood, McCarthy, & Chaplin, 2017). The evidence suggests that the nature of measures that force individuals into discrete categories can mean that there may be errors in classification, with the way an individual presents on one day meaning they are classified as moderate, whereas the next they could be classified as severe.

Until recently, autism was classified into low- and high-functioning, with a qualitative study of UK autism community members stating in 2016 that this classification is overly simplistic and has potentially damaging effects (Falck-Ytter et al., 2013; Kenny et al., 2016). The terms low- and high-functioning were not derived from a diagnostic manual, but rather a colloquial convention used by researchers to refer to an individual's intellect, verbal ability, or level of social ability (Kenny et al., 2016). Autistic individuals may be gifted in certain areas but extremely challenged in others, and individuals labelled as low-functioning may possess exceptional talents. It has been argued that severity cannot be determined based on one measure alone, such as intelligence scores (Tate, 2014). An individual's verbal ability, or the extent to which they need help on a day-to-day basis, cannot be used to determine functioning or severity (Tate, 2014). However, very little is known about the 30% of autistic individuals who are minimally verbal (Tager-Flusberg & Kasari, 2013). As Grandin and Panek (2013) put it, 'the problem with the research…is that autistic people don't all have the same sensory problems' (pg. 106-107). This brings about research-related issues, with heterogeneity in the way the condition is expressed, and changes throughout development, which means that it is difficult to categorise people into discrete categories for research (Dinishak, 2016).

Given this difficulty in research, and the variation in the expression of autism symptoms, the aim of this chapter is to use various measurement techniques to provide quantifiable demographic scores for the participants, to aid clarity of the volunteers, to support cross-study comparison, and to facilitate the methods being replicated. The measures that will be used in this chapter will each focus on different attributes: social, sensory, verbal understanding and vocabulary, and motor ability. This chapter is the starting point for this programme of work, in which participants will be screened for participation in further studies. For example, identifying processing delays, restricted and repetitive behaviours that would affect the completion of a task, and co-morbidities. In doing this, the researcher will attempt to gauge the cognitive ability, social responsiveness, language capabilities and understanding, sensory processing, and restricted and repetitive behaviours of participants. This will then be used to appropriately design further studies so that they are inclusive and suitable to the participant's needs, with flexible arrangements that can work around participants.

Method

Participants

There was a total of 71 participants, comprised of 37 minimally verbal individuals. These individuals were split into two groups based on their retrospectively calculated number of hours trampolining. The trampolining group was 76% minimally verbal, and the non-trampolining group was 55% minimally verbal.

The trampolining group receive one hour of trampolining or rebound therapy per week as part of their engagement with the AutismAbility project. Retrospective calculation using their start date on the project, the number of sessions per year, the number of sessions before they trampolined independently, and sessions missed were used. In these sessions, the trampolining group complete targets to receive British Amateur Gymnastic Association (BAGA) awards, which were also used as a measure of their trampolining ability. The non-trampolining group have no trampolining experience, averaging zero hours of experience.

Participants had an existing clinical diagnosis of autism spectrum disorder and were recruited from a dedicated charity (Autism Together) that specifically caters to individuals with autism. This was an opportunity sample, recruited from a trampolining centre that ran as part of the AutismAbility project and the Social Enterprise at Bromborough Pool Village at Autism Together. Participant demographics can be found in Table 2.

Due to refusal (n = 11) or activity leaders' decision for them not to complete the assessment due to behavioural (violent or inappropriate such as trying to break the equipment) or health (recent injury or change in medication) reasons (n = 19), 30 individuals could not complete the *Movement Assessment Battery for Children Second edition* (MABC-2; Henderson, Sugden, & Barnett, 2007). These participants were coded according to an incomplete or refusal in the MABC-2 handbook. For those whom it was deemed inappropriate for the task to continue, the assessment was stopped and only the data collected up to that point was used for that individual.

Participants were approached by the researcher, their support worker, or the group lead to establish their willingness to participate. The researchers were clear that the personal interests of the participants were of the utmost importance, with all invited participants allowed as much time as necessary to make a decision regarding their involvement in the study. Where possible, consent was obtained from the participants, however, in certain cases it was necessary to refer to the Mental Capacity Act (2005) to establish a participant's capacity to make a decision. This process was facilitated by one-to-one support workers, group leads, and activity leaders. Once the capacity to consent to participate was established, all necessary measures were completed for each participant before starting the protocol. The experiment received clearance from the Liverpool John Moores University ethics committee.

Table 2. *Number of participants and participant demographics, including age and gender, for the trampolining and non-trampolining groups.*

	Trampolining Group	Non-trampolining Group	Total
Males	n = 37 21-55 years (*M* = 30.89, *SD* = 9.08)	n = 18 18-60 years (*M* = 37.44, *SD* = 13.49)	n = 55 18-60 years (*M* = 33.04, *SD* = 11.33)
Females	n = 12 20-66 years (*M* = 36.25, *SD* = 15.67)	n = 4 29-43 years (*M* = 35.75, *SD* = 5.74)	n = 16 20-66 years (*M* = 36.13, *SD* = 13.66)
Total	n = 49 20-66 years (*M* = 32.20, *SD* = 11.11)	n = 22 18–60 years (*M* = 37.44, *SD* = 12.27)	n = 71 18-66 years (*M* = 33.73, *SD* = 11.86)

Measures

To verify the existing diagnosis, participants were assessed using three different classification measures (*Verbal IQ, SP-2, and SRS-2*). Measures of experience and motor ability were also taken (hours of trampolining experience, *BAGA award*, and *MABC-2*), these are described below.

Verbal IQ.

Participants *Verbal IQ* was assessed using the 4th edition Peabody Picture Vocabulary test (Dunn & Dunn, 2007), which gives a score in relation to participant's actual chronological age. This procedure allows *Verbal IQ* to be measured in adults who are verbal, and importantly, those that are minimally verbal.

Sensory Profile.

The Sensory Profile 2 (SP-2; Dunn, 2014) evaluates an individual's sensory processing patterns at home and in community-based activities. The questionnaire evaluates an individual's unique sensory processing patterns from a position of strengths. This questionnaire corresponds to Dunn's (2014) processing pattern framework, in which there are four quadrants: registration/bystander, seeking/seeker, sensitivity/sensor, and avoiding/avoider. This runs along a neurological threshold continuum (high and low) and the self-regulation continuum (active and passive). Alongside the quadrants, associated symptoms and behaviours are used to quantify sensory processing patterns. These behaviours include conduct (how they differ from expectations), social emotional responses (the individual's expressiveness), and attentional responses (their ability to detect important stimuli, i.e. jumping from one thing to another so much it interferes with activities). Registration refers to whether the individual notices changes in the world around them; a *bystander* (high neurological threshold and passive self-regulation) is less bothered about things going on around them, and they are more likely to miss sensory cues, such as someone calling their name. Seeking refers to the amount an individual seeks out sensory input, a *seeker* (high neurological threshold and active self-regulation) will touch things, make noise, and chew things, in order to get more sensory input. *Sensors* (sensitivity) are the opposite of seekers (low neurological threshold and passive self-regulation), a sensor can easily detect differences, errors, and patterns that others might miss; this can show in patterns of asking others to be quiet, covering ears, and being picky eaters. Avoiding refers to an individual who needs things the same and routine (low neurological threshold and active self-regulation); *avoiders* create routines and order to reduce unanticipated sensory input. This may show as a choice to work alone or avoid activities.

There are summary scores for the quadrants, symptoms, and behaviours, with a rating of how the data compares to the typical population. Scores within a standard deviation from the mean is classed as *just like the majority of others*. Those between one and two standard deviations minus the mean is classed as *less than others*: the behaviour is seen less often than in the typical population. More than two standard deviations minus the mean is classed as *much less than others*: seen much less often. This pattern is the same for plus the mean, with between one and two being *more than others*, and over two standard deviations as *much more than others*.

Social Responsiveness Scale.

The Social Responsiveness Scale 2 (SRS-2; Constantino & Gruber, 2012), was used to measure the severity of autism spectrum disorder. It obtains first-hand ratings from individuals who have observed the individual in naturalistic social settings (parents or support workers) (Constantino et al., 2003). The questionnaire corresponds to six symptoms of autism: social awareness, social cognition, social communication, social motivation, restricted interests and repetitive behaviours, and social communication and interaction. The 65-item questionnaire uses a 4-point Likert scale ranging from 0 (never true) to 3 (almost always true) in order to rate participants and produces an overall severity *t*-score. Standard scores (*t*-score) from 60 to 75 indicates “mild to moderate autism” 76 or higher indicates “severe” autism, which are compatible with the DSM-V criteria. There are also compliant symptoms of social communication and interactions and restricted and repetitive behaviours.

Movement Assessment Battery for Children.

The Movement Assessment Battery for Children Second Edition (MABC-2; Henderson, Sugden, & Barnett, 2007) is a standardised assessment to measure motor skills and has been found to be valid and reliable in the autistic population (Liu & Breslin, 2013). After piloting and from the advice of the team leaders and support workers, it was decided that the 3-6 years' age band was the most appropriate for the participants to attempt. This was due to the level of understanding of the participants, as well as their capacity to complete the sections with as little stress and anxiety as possible. For example, for the aiming and catching section, it is known that autistic individuals have difficulties in controlling the force and direction of throwing a ball (Staples & Reid, 2010). Therefore, the participants would not be expected to perform at a typical standard for their age.

Procedure

The measures were collected on two different sites: The Drill Centre (for the trampolining group) and in the Social Enterprise (for the non-trampolining group). Within both centres, the experiment took place in an environment that was familiar and quiet, with moderate lighting, and minimal distractions, so that the participants would feel as comfortable as possible. The measures in this chapter were not conducted in a set order or within a set time-frame, this was so that the collection was as flexible and accommodating as the participant needed. If the support workers reported that the participant had not had a good morning/day/week, then which test, if any, was suitable were discussed, with the participants wellbeing always the priority.

Participants performed the protocols individually; if participants required a support worker, they were present during the session along with the team leader and researcher. The support worker and team leader sat next to the participant, and relayed instructions from the researcher if the participant preferred this. Participants were asked to read the information sheet and consent form and asked to sign their name if they wished to participate. The information sheet and experiment were outlined verbally to make sure that the participant understood the instructions, and then there was time for any questions from the participant, support worker, or team leader.

Verbal IQ.

Verbal IQ (Dunn & Dunn, 2007) consists of a booklet, with four pictures on each page; the researcher reads out a word and the participant is required to point to the corresponding picture. The researcher uses a record form to note down which answer the participant gives, which is used to calculate their score later. The Peabody Picture Vocabulary test is untimed; however, participants who do not respond within 10 seconds are encouraged by the researcher to give a response. If a participant does not answer a question, it is counted as an error; the test continues until there are eight errors.

Sensory Profile and Social Responsiveness Scale.

The SP-2 (Dunn, 2014) and *SRS-2* (Constantino & Gruber, 2012) questionnaires were administered to support workers or activity leaders as they were in the best position to observe the individual's response to sensory and social interactions that occurred throughout the day. *The SP-2* (Dunn, 2014) and *SRS-2* (Constantino & Gruber, 2012) both take 20 minutes to fill out.

Movement Assessment Battery for Children.

As a measure of motor ability, the *MABC-2* (Henderson et al., 2007) was used to assess aiming and catching, manual dexterity, and balance; the tasks are listed in Table 3. All tasks were measured in the time to completion, except the drawing trail and walking with heels raised were measured in the number of errors made. For tasks with two attempts, the preferred hand or leg (being the one the participant automatically started with) was compared to the non-preferred hand or leg. The tasks can be completed in any order and split over several days; this was decided between the researcher, team leader, and support workers as the best way to reduce anxiety for the participants.

Table 3. *Tests and tasks for the MABC-2 (Henderson et al., 2007).*

Tests	Tasks		
Aiming and Catching	Catching beanbag (five practice, ten recorded)	Throwing beanbag onto mat (five practice, ten recorded)	
Manual Dexterity	Posting coins (two attempts)	Threading beads (two attempts)	Drawing trail
Balance	One-leg balance (two attempts)	Walking heels raised (two attempts)	Jumping on mats (two attempts)

Data Analysis

Independent *t*-tests were used to compare scores between the groups (trampolining and non-trampolining) to see if there were any significant differences.

Results

Verbal IQ

An independent samples *t*-test was conducted to compare *Verbal IQ* scores in the trampolining group and the non-trampolining group. The Levene's test was violated ($p < 0.05$), so equal variance was not assumed. When this was adjusted for, there was a significant difference found between the groups (t (29.95) = -2.55, $p < 0.05$). The trampolining group have on average a lower *Verbal IQ* score (31.35 ± 18.47) than the non-trampolining group (47.64 ± 27.32).

The lowest score that could be achieved on the Peabody Picture Vocabulary Test Fourth Edition (Dunn & Dunn, 2007) is 20. Of the 71 participants that took part in this assessment, 38 individuals scored 20, 62 individuals scored below 70, and only 1 participant scored above 100. A score of 70 and below is classified as having learning difficulties (American Psychiatric Association, 2013), 87% of this sample obtained a score in this range. This means that participants may need extra time for processing delays.

Sensory Profile

Quadrant scores for the trampolining and non-trampolining groups can be found in Table 4. The percentage of participants in each group who fit into these categories for each quadrant can be seen in Table 5. Independent samples *t*-tests were conducted to compare quadrant scores in the trampolining group and the non-trampolining group. There were significant differences in the scores for seeking, t (69) = 3.83, $p < 0.05$; avoiding, t (69) = 3.77, $p < 0.05$; sensitivity, t (69) = 3.92, $p < 0.05$; and registration, t (69) = 3.10, $p < 0.05$. The trampolining group scored higher in each of the quadrants than the non-trampolining group, meaning the trampolining group has sensory processing patterns that are further from the norm than the non-trampolining group's sensory processing patterns. The trampolining and non-trampolining groups had the highest scores in the avoiding/avoider and registration/bystander quadrants, which means these are the quadrants that will predominantly impact sensory processing patterns.

Table 4. *The SP-2 mean quadrant scores and standard deviations for the trampolining and non-trampolining groups.*

	Trampolining Group M (SD)	Non-trampolining Group M (SD)	
Seeking	41 (12.11)	29 (12.49)	*
Avoiding	55 (10.91)	44 (13.28)	*
Sensitivity	47 (10.40)	36 (13.18)	*
Registration	50 (11.47)	39 (15.95)	*

$p < 0.05$*

Table 5. *Percentage of participants in each quartile for the quadrant scores for the trampolining and non-trampolining groups.*

		Trampolining Group (%)	Non-Trampolining Group (%)
Seeking	Much Less	0	5
	Less	0	9
	Majority	59	77
	More	35	5
	Much More	6	5
Avoiding	Much Less	0	0
	Less	0	0
	Majority	20	55
	More	47	41
	Much More	33	5
Sensitivity	Much Less	0	0
	Less	0	0
	Majority	31	68
	More	41	18
	Much More	29	14
Registration	Much Less	0	0
	Less	0	0
	Majority	39	77
	More	39	9
	Much More	22	14

To quantify these quadrants, the questionnaire corresponds to the 6 different processing senses: auditory, visual, touch, movement, body position, and oral. This information for the groups can be found in Table 6, the percentages of participants in each quartile can be seen for symptom scores across the groups in Table 7.

Independent samples *t*-tests were conducted to compare symptom scores in the trampolining group and the non-trampolining group. For the auditory symptom, the Levene's test was violated ($p < 0.05$), so equal variance between the groups could not be assumed. When this was adjusted for, there was a significant difference between the groups when this was accounted for, t (29.20) = 3.36, $p < 0.05$. There were significant differences in the scores for the symptoms: visual, t (69) = 4.90, $p < 0.05$; touch, t (69) = 6.58, $p < 0.05$; movement, t (69) = 3.36, $p < 0.05$. The trampolining group scored higher than the non-trampolining group for auditory, visual, touch, and movement symptom scores. However, there were no significant differences found in the scores for body position, t (69) = 0.04, $p > 0.05$; and oral symptoms, t (69) = 1.45, $p > 0.05$.

Higher scores are associated with that symptom/behaviour being more frequent. The highest score for the trampolining and non-trampolining groups was in auditory symptom. This means that the bystander and avoider behaviours are seen in auditory situations more than others are. This suggests a low threshold pattern for sounds, this could include avoiding sounds that are not typical for that situation (e.g. hearing a fire alarm could cause distress) or being unaware of sounds that typical people would be attuned to (e.g. hearing one's name being called, not being aware of someone giving instructions such as to stop doing an activity).

Table 6. *The SP-2 mean symptom scores and standard deviations for the trampolining and non-trampolining groups.*

	Trampolining Group M (SD)	Non-trampolining Group M (SD)	
Auditory	23 (4.68)	18 (7.22)	*
Visual	14 (4.47)	8 (5.73)	*
Touch	24 (5.10)	15 (6.48)	*
Movement	18 (5.66)	13 (6.02)	*
Body Position	13 (4.17)	13 (6.35)	
Oral	18 (7.15)	15 (8.66)	

$p < 0.05$*

Table 7. *Percentage of participants in each quartile for the symptom scores for the trampolining and non-trampolining groups.*

		Trampolining Group (%)	Non-Trampolining Group (%)
Auditory	Much Less	0	0
	Less	0	9
	Majority	53	68
	More	41	23
	Much More	6	0
Visual	Much Less	2	23
	Less	4	18
	Majority	63	55
	More	18	0
	Much More	12	5
Touch	Much Less	0	0
	Less	0	18
	Majority	16	68
	More	59	14
	Much More	24	0
Movement	Much Less	0	0
	Less	2	9
	Majority	41	73
	More	35	9
	Much More	22	9
Body Position	Much Less	0	0
	Less	0	0
	Majority	76	68
	More	10	14
	Much More	14	18
Oral	Much Less	0	0
	Less	0	9
	Majority	78	77
	More	18	9
	Much More	4	5

Behaviours associated with sensory processing can be found in Table 8, the percentages of participants in each quartile can be seen for behavioural scores across the groups in Table 9. Independent samples *t*-tests were conducted to compare behaviour scores (associated with sensory processing) in the trampolining group and the non-trampolining group. There were significant differences in the scores for conduct, t (69) = 2.55, $p < 0.05$; social emotional responses, t (69) = 3.34, $p < 0.05$; and attentional responses, t (69) = 2.57, $p < 0.05$. The trampolining group scores higher than the non-trampolining group for all behaviours, this means that the trampolining group would exhibit more behaviours associated with sensory processing that would be considered to deviate from the norm than the non-trampolining group. It would be expected from these scores that participants would not follow the unwritten rules of society (e.g. getting very close to other people); would not express themselves or respond to others typically (e.g. is indifferent to another person whether they are sad or happy); their attention is also short (e.g. getting distracted by lights on a monitor when watching a video).

Table 8. *The SP-2 behavioural mean scores and standard deviations for the trampolining and non-trampolining groups.*

	Trampolining Group M (SD)	Non-trampolining Group M (SD)	
Conduct	20 (5.64)	17 (6.42)	*
Social Emotional	41 (8.33)	33 (10.32)	*
Attentional	28 (8.19)	23 (7.93)	*

$p < 0.05$*

Table 9. *Percentage of participants in each quartile for the behavioural scores for the trampolining and non-trampolining groups.*

		Trampolining Group (%)	Non-Trampolining Group (%)
Conduct	Much Less	0	0
	Less	0	5
	Majority	55	68
	More	39	23
	Much More	6	5
Social Emotional	Much Less	0	0
	Less	0	0
	Majority	4	41
	More	55	41
	Much More	41	18
Attentional	Much Less	0	0
	Less	0	0
	Majority	35	55
	More	20	23
	Much More	45	23

The Social Responsiveness Scale

The SRS-2 (Constantino & Gruber, 2012) measures social impairments and can be used (through the *t*-score and DSM compatible scores) to quantify severity. The scores for each symptom are shown in Table 10.

Independent samples *t*-tests were conducted to compare symptom scores in the trampolining group and the non-trampolining group. There were significant differences in the scores for social awareness, t (69) = 2.88, $p < 0.05$; social communication, t (69) = 3.53, $p < 0.05$; social motivation, t (69) = 2.88, $p < 0.05$. However, the Levene's test was violated ($p < 0.05$) for some symptoms, so equal variance could not be assumed. When this was adjusted for, there were significant differences in social cognition, t (27.97) = 2.83, $p < 0.05$; restricted interests and repetitive behaviours, t (28.74) = 4.04, $p < 0.05$; and social communication and interaction, t (32.78) = 3.23, $p < 0.05$. The trampolining group scored higher than the non-trampolining group for all symptom scores, this means that the trampolining group could be considered as more severe and would be expected to display more social behaviour differences than the non-trampolining group.

Table 10. *SRS-2 symptom score means and standard deviations for the trampolining and non-trampolining groups.*

	Trampolining Group M (SD)	Non-Trampolining Group M (SD)	
Social Awareness	74 (12.24)	65 (11.92)	*
Social Cognition	77 (8.32)	68 (13.91)	*
Social Communication	76 (9.31)	66 (12.35)	*
Social Motivation	67 (10.64)	59 (11.23)	*
Restricted Interests and Repetitive Behaviours	78 (7.78)	66 (12.36)	*
Social Communication and Interaction	76 (9.78)	66 (12.63)	*

$p < 0.05$*

There is a standardised *t*-score for the *SRS-2*, which is an overall score taken across symptomology. There was a significant difference between the scores, $t\ (49) = 2.97$, $p < 0.05$. The trampolining group (77 ± 9.28) scored higher than the non-trampolining group (66 ± 12.05), meaning that the trampolining group would be classified as more severe than the non-trampolining group. A score of 59 and below is considered within normal limits, 60-65 is a mild score, 66-75 is a moderate score, and 76 or higher is considered severe. The trampolining group would be classified as severe and the non-trampolining group would be classed as moderate. The percentage of participants in the DSM-V compliant symptoms range can be seen in Table 11.

Using the *t*-scores and the DSM-V compliant symptoms (restricted interests and repetitive behaviours, and social communication and interaction), the trampolining group would be classified as having severe autism, whereas the non-trampolining group would be classified as moderate autism spectrum disorder (American Psychiatric Association, 2013; Constantino et al., 2003). The trampolining group is consistently in the severe range, and the non-trampolining group in the moderate range. With the exceptions to this being in social awareness and social motivation where both groups drop a level, the non-trampolining group being in the mild and normal range, respectively, and the trampolining group being in the moderate range for both.

Table 11. *Percentage of participants in each symptom range for the DSM-V compliant symptoms for each group.*

		Trampolining Group (%)	Non-Trampolining Group (%)
Within Normal Limits	RRB	2	32
	SCI	8	32
	t-score	6	32
Mild	RRB	4	14
	SCI	10	9
	t-score	2	9
Moderate	RRB	24	27
	SCI	14	32
	t-score	20	36
Severe	RRB	67	27
	SCI	65	27
	t-score	69	23

Experience

The trampolining group had their *hours of experience* in trampolining calculated (the non-trampolining group had no experience). The average number of hours for the trampolining group was 121.61 (*SD* = 49.49), and the average number of hours for the non-trampolining group was zero.

The average BAGA trampolining proficiency award level for the trampolining group was 3 (*SD* = 2.15), with the highest in the group achieving a 9 and the lowest being a 1. Award level 1 requires an individual to demonstrate waiting and good behaviour on the trampoline, mount and dismount from central position, move freely around the trampoline, sitting and bouncing, standing and bouncing, lying on back and being bounced, and hands and knees bouncing. Award level 9 requires an individual to demonstrate front landings, back landings, front landing to back landing to feet, back landing to front landing to feet, forward ¾ turnover to back landing to feet, seatdrop to full twist to seat to feet, backwards roll, and a full routine of (full twist, straddle, seatdrop, ½ twist to seatdrop, ½ twist to feet, pike, back landing, ½ twist to feet, tuck, ½ twist).

Movement Assessment Battery

Movement Assessment Battery for Children Second edition (Henderson et al., 2007) scores for the trampolining and non-trampolining groups can be seen below in Table 12. Independent samples *t*-tests were conducted to compare standard scores of fine and gross motor abilities in the trampolining group and the non-trampolining group. There were no significant differences found in the aiming and catching task, $t\ (69) = -1.12$, $p > 0.05$. The Levene's test was violated ($p < 0.05$) for some tasks, so equal variance could not be assumed. When this was adjusted for, there were no significant differences in balance, $t\ (29.26) = -1.82$, $p > 0.05$, or the total test standard score, $t\ (34.77) = -1.82$, $p > 0.05$. However, there was a significant difference found in manual dexterity, $t\ (69) = -2.04$, $p < 0.05$. The non-trampolining group scored higher on manual dexterity, this means that the non-trampolining group have better fine motor abilities than the trampolining group, though this should not impact the subsequent studies in the current thesis.

Table 12. *Movement Assessment Battery mean standard scores and standard deviations for each task and the total assessment for the trampolining and non-trampolining groups.*

	Trampolining Group M (SD)	Non-trampolining Group M (SD)	
Manual Dexterity Score	6 (6.82)	10 (6.71)	*
Aiming and Catching Score	6 (5.33)	7 (5.36)	
Balance Score	3 (2.84)	5 (4.37)	
Total Test Score	5 (4.69)	7 (5.60)	

$p < 0.05$*

The MABC can also be used to identify if a participant requires an intervention to assist with their movement difficulties, if they are found to have them. Table 13 shows the percentages of participants in each group who fit into these categories. This works on a traffic light system: red being significant movement difficulties, participants score at or below the 5th percentile in their total test score. Amber being at risk of movement difficulties, participants score falls between the 5th and the 15th percentile in their total test score, monitoring is required when this is scored. Green is above the 15th percentile in their total test score, no movement difficulty was detected during the assessment, reflected in their total test score. Sixty-three per cent of the participants in this sample are classified as having a significant movement difficulty, with their total test score derived from the aged 3-6 years age band assessment they completed.

Table 13. *Percentage of participants in each percentile category for the trampolining and non-trampolining groups.*

	Trampolining Group (%)	Non-Trampolining Group (%)
Significant movement difficulty	69	50
At risk of movement difficulty	4	5
No movement difficulty	27	45

Discussion

The aim of this chapter was to use various measurement techniques to provide quantifiable demographic scores for the participants, to aid clarity of the volunteers, to support cross-study comparison, and to facilitate the methods being replicated. This multiple measure approach, is inclusive to individuals requiring level three support (very substantial support), and is advantageous to research; as it is more representative as a sample (Underwood et al., 2017). Using multiple measures gives a more comprehensive view of each participant as an individual, and omits the arbitrary cut offs, with variability and heterogeneity seen across all measures in this chapter. The combined measures from this chapter verify the diagnosis of autism in all participants in this sample. There were differences found in verbal IQ, sensory processing, social responsiveness, and movement ability which indicate differences from the typical population, summarised in Table 14.

Table 14. *Summary of findings for the trampolining and non-trampolining groups.*

Measure	Findings	What this means
Verbal IQ	Non-trampolining group have a higher verbal intelligence standard score than the trampolining group.	87% could be classified as having a learning difficulty, participants must be treated with a level of understanding.
SP	Trampolining group score higher than the non-trampolining group for the quadrants: seeking, avoiding, sensitivity, and registration quadrants. Trampolining group score higher than the non-trampolining group for the senses: auditory, visual, touch, movement Trampolining group score higher than the non-trampolining group for the symptoms: conduct, social emotional, and attention.	Both groups have highest scores in avoiding and registration quadrant, frequently expressed through the auditory symptom, and associated with social emotional behaviours. Though the trampolining group may exhibit more sensory processing associated behaviours.
SRS	Trampolining group score higher than the non-trampolining group for the symptoms of social awareness, social cognition, social communication, social motivation, restricted and repetitive behaviours, social communication and interaction, and *t*-score.	Trampolining group classed as severe, non-trampolining group classed as moderate. The trampolining group may exhibit less social responsive behaviours.
MABC	The non-trampolining group scored higher on manual dexterity than the trampolining group.	The non-trampolining group have better fine motor abilities than the trampolining group.

Verbal IQ

There were differences found between the groups in all four measures. This included a difference between the groups in *Verbal IQ* (Dunn & Dunn, 2007) scores, which could impact upon understanding of tasks and concepts in further studies in this thesis. Studies will need to be adapted in order to be more inclusive of participants with lower scores, which could indicate a lower threshold for understanding. Instructions and tasks will have to be kept simple to be inclusive of participants who scored the lowest possible score on our measure (a score of 20). A score of 70 and below is classified as having learning difficulties (American Psychiatric Association, 2013), 87% of this sample obtained a score in this range. This adds to the heterogeneity of the sample and means the participants must be treated with a level of understanding, for example, extra processing time for processing delays, as this is a proxy for what level of support the individual needs (Lord & Bishop, 2015). It is thought that 30% of individuals with autism are minimally verbal (Tager-Flusberg & Kasari, 2013), however in this sample 69% of participants were minimally verbal, which can be something to keep in mind for a researcher to expect fundamental motor skill difficulties (Charman et al., 2011; Kaur et al., 2018; Staples & Reid, 2010; Travers et al., 2018; Westendorp et al., 2011).

Movement Assessment Battery for Children

There were no significant differences in the groups for the *Movement Assessment Battery for Children* scores (with the exception of the manual dexterity) (Henderson et al., 2007). This means the motor system and physical abilities of the groups have developed and function in the same way; this is important for further studies in this thesis. Any differences found between the trampolining and non-trampolining group cannot be attributed to the trampolining group being more physically able or having a further developed motor system (Stevens et al., 2000). As previously mentioned, the participants completed the aged 3-6 years age band, due to the participant's ability to understand and complete the tasks successfully. The older age bands proved too difficult and stressful for participants during pilot testing, so the lowest age band was used. However, for adults aged 18-66 years, in a typical population, it would not have been expected to be a problem to complete any of the higher age band tasks. This finding reiterates that due to understanding, and possibly physical ability, tasks will have to be adapted to suit the participant's abilities and to be more inclusive to those at the more severe end of the sample. If the participants had trouble with tasks designed for 3-6-year olds, protocols traditionally used in the typical population will be unachievable, and it would be unreasonable to expect them to participate.

Difficulties in a motor ability test to this extent would be expected from individuals at the severe end of the spectrum (requiring level three support) (Crippa et al., 2015; Papadopoulos et al., 2012; Rinehart et al., 2006; Stoit et al., 2013). It would be expected that this sample would also have difficulties in social interactions (Cummins et al., 2005; MacDonald et al., 2013; Mostofsky & Ewen, 2011), and poor activity levels, which would negatively impact quality of life (Cummins et al., 2005; Lang et al., 2010; Petrus et al., 2008). Previous research (Esposito & Venuti, 2009; Kindregan, Gallagher, & Gormley, 2015; Mache & Todd, 2016; Papadopoulos et al., 2012; Rinehart et al., 2006; Stoit et al., 2013; Travers et al., 2018; Travers et al., 2013; Weiss, Moran, Parker, & Foley, 2013) suggests that deviations from standards of the typical population are to be expected from the autistic population. In this sample, 69% of the participants would be considered to have a significant motor difficulty. Since this was based on an aged 3-6 years measure, this indicates very significant motor problems in this sample. This suggests that this sample has difficulties with adaptive behaviour skills and daily living skills (MacDonald et al., 2013).

For the current thesis, this means that because there are no significant differences in gross motor ability, that the only difference in the sensorimotor systems of the trampolining and non-trampolining groups should be that one has sensorimotor experience of trampolining and the other group does not. Therefore, any conclusions drawn from differences in perception data can be discussed as experience dependent differences. Differences in gross motor ability may impact the internal action models used in identification and evaluation of stimuli, though there were differences found in fine motor ability (manual dexterity), this should not impact perception of gross motor movements (examined in latter chapters).

Sensory Profile

The *Sensory Profile* (Dunn, 2014) measures non-social aspects of autism, referred to as hyper- and hypo-sensitivities (Chambon et al., 2017). Sensory seeking behaviours are an important aspect of this study, as the stimuli used in further studies can be adapted to minimise distress that could be caused by sensory overload; this means that sensory information such as visual, auditory, vestibular, or proprioceptive needs to be controlled (Baker et al., 2008; Tomchek & Dunn, 2007; Turi et al., 2017). This environment can be achieved by limiting the use of fluorescent lights in testing areas, clearing areas of items that could be distracting to participants, limiting (where possible) foot traffic through areas or activities that are considered noisy, and using equipment that the participants are used to seeing and touching. Using chairs from the activity centres for the participant to sit on while they complete a task, as different fabric on the seat could cause anxiety or lead to restricted and repetitive behaviours due to arousal.

Differences were found in all quadrants of the *Sensory Profile*, for all symptoms (except body position and oral symptoms), and all behaviours of the *Sensory Profile*. In terms of the definitions given by Dunn (2014), participants tend to miss sensory cues (bystander) and are very routine-based (avoider). This would fit with a diagnosis of autism spectrum disorder (American Psychiatric Association, 2013), for persistent deficits in social communication and interactions across multiple contexts, and restricted and repetitive patterns of behaviour. These behaviours are seen more in auditory behaviours (the highest symptom score), and much more than the typical population for conduct, social emotional, and attentional behaviours.

There may be differences to what would typically be expected in eye-tracking studies, for example, in scan paths and when observing stimuli that is rhythmic in its movements. However, in the visual symptom, only 39% of participants differed from “just like the majority of others”; this would indicate that the individuals in this sample should not show any seeking, avoiding, sensitivities, or registration differences to the typical population. Therefore, something as non-intrusive as an eye-tracker would be ideal to use with the individuals in this sample. However, data from these participants cannot be extrapolated to the typical population and must only be used to compare within the groups in this sample, rather than to other autistic individuals. This is due to the heterogeneity seen in the autistic community, but also due to the severity of the individuals in this sample.

Social Responsiveness Scale

All symptoms of the *Social Responsiveness Scale* (Constantino & Gruber, 2012), including the DSM-V (American Psychiatric Association, 2013) compatible scores, are significantly different between the groups, however these scores did confirm that the individuals in this sample have a diagnosis of moderate to severe autism spectrum disorder, across the DSM-V compatible symptom scores and the *t*-score. This means that the participants in this sample typically do not engage in emotionally appropriate reciprocal social interactions (Constantino et al., 2003); participants experience social anxiety due to these problems (Bellini, 2004). However, there is a lot of heterogeneity in this sample, with some individuals (28% of the sample) falling into the within normal limits and the mild range, however, all participants have a pre-existing diagnosis of autism. For this sample of participants, heterogeneity does not necessarily mean that these individuals would not receive a diagnosis of autism spectrum disorder, some individuals may not have an issue with one task in an assessment, but may struggle greatly in others areas of daily functioning (Haythorne & Seymour, 2016; Tate, 2014).

Comparison of Measures to ADOS

The measures in this chapter were a preliminary assessment of the sample of potential participants who could take part in the subsequent studies in later chapters. Known variation in expression of autistic traits and the heterogeneous nature of autism, means that differences in verbal ability, sensory processing patterns, social responsiveness, and motor abilities had to be examined in order to inform the procedures of subsequent studies to be modified, if needed. The measures used in this chapter do not follow the traditional dyad of symptoms that are set out in the DSM (American Psychiatric Association, 2000, 2013), but it was thought that the combination of different measures together gave a better picture of the participants, compared to using a single diagnostic measure, such as the autism diagnostic observation schedule (ADOS-2) (Lord et al., 2012b). Even though it is described as the gold standard measure of observational assessment for autism (Kanne, Randolph, & Farmer, 2008), it is not the case for individuals requiring level three support. The adult module of the test requires the participant to be fluently verbal; most participants in this research are minimally verbal. This means that generally this sample would not be able to complete 13 of the 15 tasks in the adult module (module 4) (Lord et al., 2012b). The only module that is the exception to this (the requirement to be verbal) within the ADOS-2 is the Toddler module (Lord et al., 2012a). However, it was deemed unsuitable to use this module for our studies, activities and materials in the Toddler module may not be interesting or appropriate for use with adults. In addition, items used to score behaviour in young children may not extrapolate to older individuals (Hus et al., 2011). Therefore, there would be poor population and ecological validity, as it is intended for use with children under 30 months (Lord et al., 2012a).

Summary

The aim of this chapter was to use various measurement techniques to provide quantifiable demographic scores for the participants, to aid clarity of the volunteers, to support cross-study comparison, and to facilitate the methods being replicated. *Verbal IQ* indicated that there is a high chance of intellectual disability in this group, with 54% of individuals in this sample scoring the lowest possible score. This means that instructions and task design will have to be modified and flexible in the thesis so that processing delays and difficulties in understanding do not mean that an individual cannot participate because this has not been addressed. *The Sensory Profile* indicated that the participants will display more avoiding behaviours, particularly in the auditory and touch symptoms and attention behaviours. *The Social Responsiveness Scale* indicated that participants are within the moderate to severe symptom range, which means participants may have difficulty with social communication and interactions and have many restricted and repetitive behaviours. This was reflected in the motor ability test, there were no differences between the groups (expect in manual dexterity), meaning the motor system has developed similarly between the groups. Therefore, the difference between the groups is that one has sensorimotor experience of trampolining and the other does not.

Chapter Three: Comparative Evaluation of Automatic Imitation in Adults with Moderate to Severe Autism

Abstract

It has long been thought that individuals with autism cannot imitate (Leighton, Bird, Charman, & Heyes, 2008; McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006; Vanvuchelen, Roeyers, & De Weerdt, 2011; Zachor et al., 2010). However, many recent studies have suggested this is not the case (Bird et al., 2007; Hayes et al., 2016a; Heyes, Bird, Johnson, & Haggard, 2005; Sowden et al., 2016; Spengler, Bird, & Brass, 2010). Typically, individuals with mild autism (or Level One) are chosen to participate in imitation studies, meaning that not a lot is known about how individuals with more severe autism imitate. In the current study, therefore, participants with moderate to severe autism completed an automatic imitation protocol described by Brass et al. (2000). Participants observed a video of a hand either lifting the index or middle finger, which was either compatible or incompatible with the required response of lifting their index or middle finger. Participants exhibited an automatic imitation effect, in which the response in incompatible trials had slower reaction times than compatible trials, as well more errors. These data show that adults with moderate to severe autism demonstrate a functional sensorimotor system through automatic imitation. This is important for subsequent chapters in which the effect of sensorimotor experience on perception is examined. Specifically, predictions can be made in subsequent chapters based on the perception-action link examined here, as well as intact sensorimotor functioning, as would be expected from the typical action observation literature.

Introduction

In humans, imitation is an important mechanism for learning social behaviours, where an individual observes an action and performs a similar action (Heyes, 2001). Imitation has many definitions, but what remains constant is the capacity of the individual to replicate an observed action following observation (Tomasello, Carpenter, Call, Behne, & Moll, 2005). Imitation can help individuals to pick up culturally appropriate behaviours without being actively taught (Blandin et al., 1999; Prinz, 1997; Tomasello et al., 2005), and encourages a prosocial orientation in the observer as social factors modulate processing of the observed action (see STORM; Wang & Hamilton, 2012); and imitating gestures and actions shows empathy and affiliation (Lakin & Chartrand, 2003; Van Baaren, Holland, Kawakami, & Van Knippenberg, 2004). Imitation is underpinned by the creation of a representation of the observed actions through a process of sensorimotor integration or the use of an existing representation if the action is already known (Vivanti & Hamilton, 2014; Wilson & Knoblich, 2005). In either case, the imitator needs a functional motor system to execute the action to successfully imitate the observed action (Vivanti & Hamilton, 2014).

The impact of the autistic motor system on voluntary imitation has been demonstrated in previous studies of discrete (Glazebrook, Elliott, & Lyons, 2006) and sequential aiming movements (Roberts, Elliott, Lyons, Hayes, & Bennett, 2016), cyclical arm movements (Cook et al., 2013), and goal-directed and goal-less movements (Wild et al., 2012). The current viewpoint is that although autistic individuals do not show the same behaviour following observation as typical controls, they do nonetheless exhibit functional imitation. Autistic adults exhibit less accurate motor timing, however, following practice and feedback autistic adults exhibit improved performance in timing and less errors to a similar extent as typical controls (Hayes et al., 2018). However, many of the tasks used to examine voluntary imitation place substantial demands on the participant's executive function and attentional control, which can be difficult for people with autism (Bird et al., 2007; Frith & Frith, 2006; Rogers, Hepburn, Stackhouse, & Wehner, 2003). This is even more relevant in autistic individuals with moderate to severe autism who have difficulty with cognitive ability and verbal understanding (Vanvuchelen et al., 2011). Therefore, to better understand the imitation ability of autistic individuals it can be useful to minimize the need for cognitive involvement in task understanding, motor planning and feedback processing.

Brass et al. (2000) used an automatic imitation task to investigate the relationship between movement observation and movement execution through the comparison of ideomotor-compatible stimuli alongside symbolic stimuli (i.e., a video of an action which matches the required action signalled by a number). The task was derived from observing individuals with 'compulsive imitative behaviour' (Brass et al., 2000, p. 125), and led to the suggestion that movement observation activates movement execution (Brass et al., 2000; Lhermitte, Pillon, & Serdaru, 1986). This is similar to the echolalia (copying speech) and echopraxia (coping actions without context or meaning) seen in autism, in which speech and behaviours are involuntarily imitated when observing others (Spengler et al., 2010). To summarise, Brass et al. (2000) found that people make a simple finger movement faster when a compatible finger movement is observed, and they are slower when it is incompatible. This automatic imitation effect is evident in reaction time (RT) and error measures that assess the impact of stimulus compatibility on motor performance (Cooper, Catmur, & Heyes, 2013; Heyes, 2011; Iacoboni, 2009; Stürmer, Aschersleben, & Prinz, 2000). It is assumed that connections between movement observation and movement execution, relevant or not, are strengthened through frequent exposure; due to the activation of sensorimotor representations associated with the observed movement (see Associative Sequence Learning; Catmur, Walsh, & Heyes, 2009). This leads to the connection becoming automatic in response to the stimulus

(Cooper et al., 2013). Connections within the automatic route can contrast with manual responses, resulting in task-irrelevant responses (Cooper et al., 2013).

The automatic imitation effect is generally reduced with inanimacy, such as when a robot performs the action (Press, Bird, Flach, & Heyes, 2005), or inanimacy is inferred (Liepelt & Brass, 2010; Tsai & Brass, 2007). However, autistic individuals show an automatic imitation effect with a greater animacy bias than typical individuals; responses to compatible trials are quicker than incompatible trials, which in turn is greater for human than robotic actions (Bird et al., 2007; Schunke et al., 2016). Differences in automatic imitation between autistic and typical participants are also found in pro-social priming, where there is no modulation from a social prime in autistic participants, but there is in typical participants where a social prime results in faster reaction times (Cook & Bird, 2012). Similarly, reaction times for autistic individuals correlated with theory of mind and reciprocal social interaction and social communication in ADOS (Spengler et al., 2010). The more severely autistic the individual, the more non-social processing differences there are thought to be, which may then effect their imitative ability (Bird et al., 2007; Smith & Bryson, 1994). This means that there is a relationship between automatic imitation in autistic individuals and social modalities, which is associated with less activation in brain areas associated with mentalising (Spengler et al., 2010).

There is other evidence to suggest that problems with imitation in autistic individuals (Leighton et al., 2008; McIntosh et al., 2006) are not explained by cognitive and motor differences (Vanvuchelen et al., 2011). Autistic individuals may have no problem on a functional level of imitation, but instead they may exhibit a problem processing the observed action into an executed action (Bird et al., 2007; Smith & Bryson, 1994; Vanvuchelen et al., 2011). This problem in processing is also thought to lead to a hyper-imitation effect, in which autistic individuals have a larger automatic imitation effect (difference between compatible and incompatible trial response times) than typical individuals (Brass et al., 2000; Foti et al., 2014; Spengler et al., 2010; Vivanti et al., 2017).

It is clear that there is a lack of consensus within the literature as to whether automatic imitation in autistic individuals is superior or inferior to typical peers. This is in part because previous research is confounded by a lack of consistency in the definition of imitation and the use of different methodologies (Levy & Mandell, 2009; Sevlever & Gillis, 2010). Here, a simple finger lifting protocol will be used to examine the research question: *is there an automatic imitation effect present in adults with moderate to severe autism?* Participants will be required to lift either their index or middle finger in response to a video that shows a human hand making either the same (compatible) or alternate (incompatible) finger movement. It is expected that results will be consistent with the previous literature with mildly autistic participants (Cook & Bird, 2012; Cooper et al., 2013; Longo & Bertenthal, 2009; Press, Gillmeister, & Heyes, 2007; Sowden et al., 2016; Spengler et al., 2010), in that compatible trials will have faster reaction times and less errors than the incompatible trials (i.e., automatic imitation effect). Adults with moderate to severe autism have not been suitably represented within the automatic imitation literature, and therefore it remains to be determined if the sensorimotor system functions in a similar way in adults with moderate to severe autism as it does in a typical individual. This is important for subsequent chapters in which sensorimotor development and functionality is investigated through perception following sensorimotor experience. If it is found here that the perception-action link is intact and therefore that the sensorimotor system is functional, it can be assumed this will not be an underlying cause of any differences found in subsequent chapters between preferential viewing in those with sensorimotor experience compared to those without sensorimotor experience.

Method

Participants

There were 10 participants, with an age range of 18–52 years (*M* = 32.50, *SD* =12.18), comprised of 2 females aged 34 and 36, and 8 males with an age range of 21-52 years (*M* = 31.88, *SD* = 13.72). This was an opportunity sample using individuals in two different sites: the drill centre (trampolining centre) in the AutismAbility project, the Social Enterprise at Bromborough Pool Village, and Gallagher House at Autism Together. Participants had normal or corrected-to-normal vision and were screened via their person-centred plans for the following exclusion criteria: dyspraxia, dyslexia, epilepsy, and other neurological or psychiatric conditions. Sample characteristics are presented in Table 15.

Participants were approached by the researcher, their support worker, or the group lead to establish their willingness to participate. The researchers were clear that the personal interests of the participants were of the utmost importance, with all invited participants allowed as much time as necessary to make a decision regarding their involvement in the study. Where possible, consent was obtained from the participants, however, in certain cases it was necessary to refer to the Mental Capacity Act (2005) to establish a participant's capacity to make a decision. This process was facilitated by one-to-one support workers, group leads, and activity leaders. Once the capacity to consent to participate was established, all necessary measures were completed for each participant before starting the protocol. The experiment received clearance from the Liverpool John Moores University ethics committee.

Table 15. *Participant Demographics.*

		Mean (*SD*)
n		10
	Gender	2 females
VIQ		52 (23)
	Age Equivalent	8 years 5 months
SRS	*t*-score	66 (9)
	AWR	61 (12)
	COG	67 (12)
	COM	64 (9)
	MOT	59 (10)
	RRB	69 (9)
	SCI	64 (9)
SP	Seeking	32 (11)
	Avoiding	51 (16)
	Sensitivity	38 (11)
	Registration	36 (12)
	Auditory	20 (6)
	Visual	11 (5)
	Touch	17 (8)
	Movement	13 (6)
	Body Position	11 (4)
	Oral	15 (6)
	Conduct	16 (4)
	Social Emotional	38 (13)
	Attentional	22 (7)
MABC	Total Test	9 (6)
	Manual Dexterity	11 (7)
	Aiming & Catching	9 (5)
	Balance	6 (4)

VIQ – Verbal IQ, measured by the Peabody Picture Vocabulary Test (fourth edition)

SRS – Social Responsiveness Scale (second edition)

SP – Sensory Profile (second edition)

MABC – Movement Assessment Battery for Children (second edition).

Stimuli

Participants watched short video clips (30 seconds in length) of a human hand presented on a black background, which was rotated to be perpendicular to the participant's hand (see Figure 2). The video showed the human hand lifting the index or middle finger (similar to Brass et al., 2000 and Sowden et al., 2016). The action the participant was required to execute was either compatible or incompatible with the action they observed. For example, a compatible trial would require the participant to lift their index finger having been shown the index finger being lifted, whereas an incompatible trial would require the participant to lift their middle finger after seeing the index finger lifted in the video.

Participants completed 60 trials in two to six sessions. In a typical session, a participant would complete 5 practice trials and then 20 experimental trials over a 10-minute period, excluding breaks. In total, there were 15 practice trials, and 60 experimental trials (30 compatible; 30 incompatible), with participants always completing practice trials before the experimental trials for those requiring more testing sessions to achieve 60 experimental trials. Trial type (compatible, incompatible) were presented in a pseudo-random order, total experiment time was 30 minutes, excluding breaks.

Design

The experimental design is within groups, involving a manipulation of condition (compatible, incompatible), and the measurement of RT (i.e., the time from stimulus onset to participant response) and the number of errors.

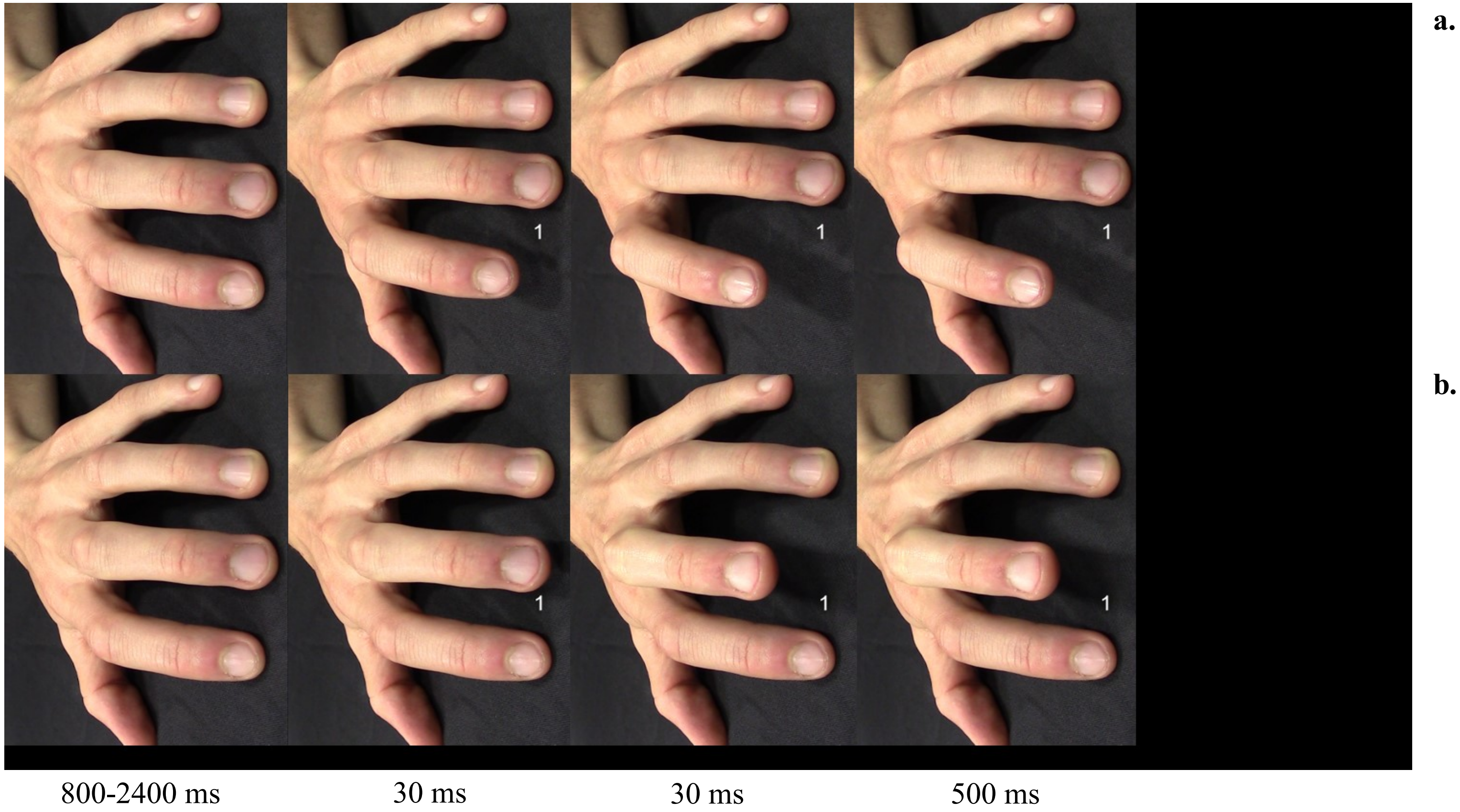

Figure 2. Five-frame action video clip used in Automatic Imitation Protocol, a) displays a compatible trial, in that the 1 requires the participant to lift their index finger which is demonstrated in the clip, and b) displays an incompatible trial, in that the 1 is displayed but the model lifts their middle finger. Frame one was displayed for a variable period (range: 800-2400 ms). Frames two and three were displayed for 30 ms each and frame four lasted 500 ms. The display durations ensured the appearance of a short video clip. The fifth frame (a black screen) remained on screen until the trial duration reached 3,000 ms and the participant had returned both fingers to the buttons on the response pad.

Procedure

The protocol was adapted from Sowden et al. (2016), in which a keyboard was used for the participants to respond to stimuli. Here, a small two-button box was used to minimise distractions, to make the protocol simpler to understand, and to be more inclusive to participants. The researcher sat at a right angle to the participant, who sat in front of a computer. The participant had their right arm on the table in front of them, and their fingers on two buttons (index finger on the left button and middle finger on the right button). The researcher described the experiment, demonstrating the finger movements that were required when the numbers appeared.

Once the participant understood the task, they were told they would get a chance to practice first before the study started. After the participants completed the practice test, the researcher checked the number of correct answers and the corresponding RTs to confirm that participants were following the task instructions. RTs from the participants lifting off the buttons was measured through MATLAB while participants watched the videos of the human hand stimulus. If participants consistently had reaction times of more than 600 ms, they were thanked for their time and the experiment was ended. If participants had reaction times of less than 600 ms on the majority of their trials, and their responses were consistently correct, the main experiment could be started. The difference between the practice and the main experiment was made clear (messages about lifting the finger off too fast, e.g. before stimulus presentation, or too slow, if over 600 ms), and then the researcher proceeded to start the MATLAB routine.

Data Analysis

Intra-participant mean data from 30 trials in each condition was calculated for RTs and number of errors, with paired-sample *t*-tests used to compare trial types. The DVs were then correlated against autism severity (SR*S* *t*-score and Verbal IQ) in Pearson correlation coefficient. Trials were discarded when RTs were less than 150 ms or greater than 2000 ms, or when responses were less than 20 ms apart, indicating a rhythmic lifting of the fingers rather than a response to the stimuli per se.

Results

Response Time Data

Group mean reaction times for the compatible and incompatible trials are presented in Figure 3. As shown, reaction times on compatible trials (mean ± standard error of the mean = 408.54 ± 15.08 ms) were faster than those on incompatible trials (464.94 ± 17.57 ms). This was confirmed by a significant difference between the reaction times on the compatible and incompatible trials, t (9) = -6.85, $p < 0.0001$. This gave rise to an average automatic imitation effect of 56.39 ms.

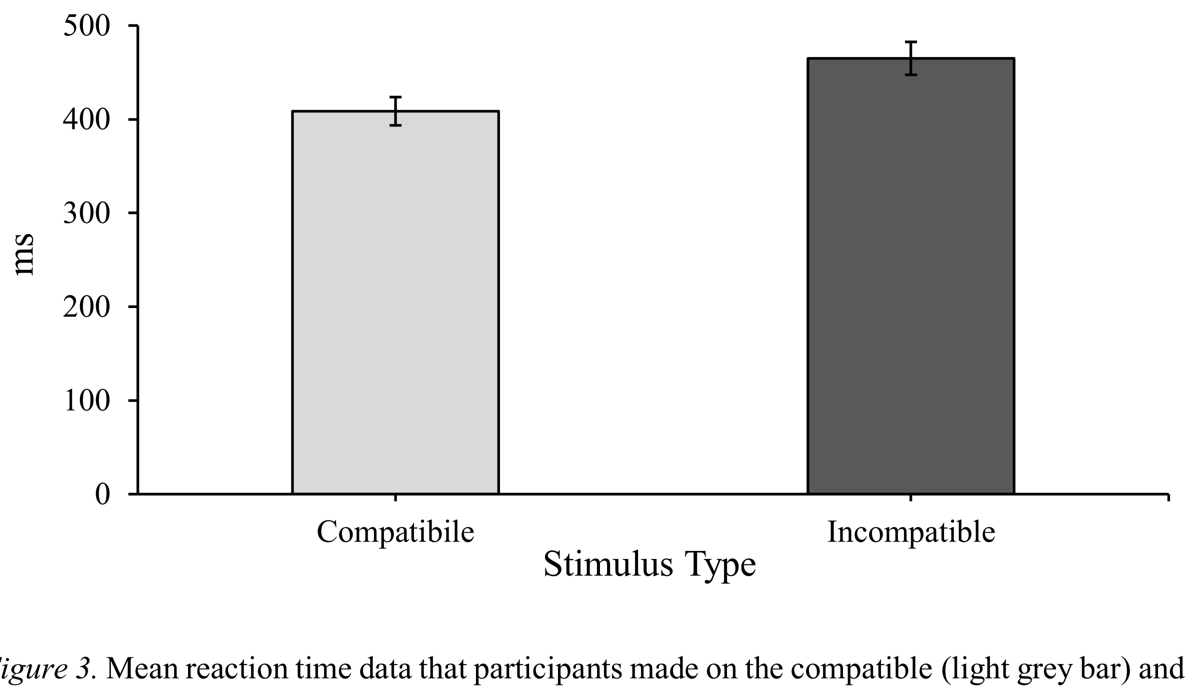

Figure 3. Mean reaction time data that participants made on the compatible (light grey bar) and incompatible trials (dark grey bar), with standard error of the mean error bars.

Autism Severity Correlations.

There was no significant correlation between the AI effect and *SRS t-score*, $r = 0.24$, $p > 0.05$ (see Figure 4), or the AI effect and Verbal IQ, $r = -0.47$, $p > 0.05$ (see Figure 5).

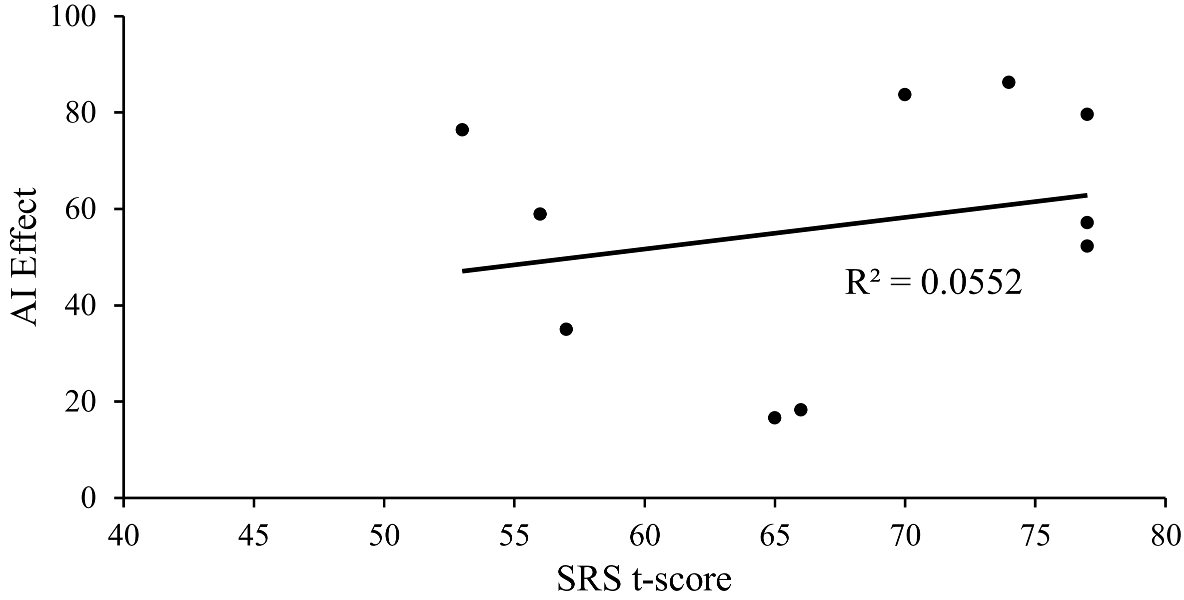

Figure 4. Scatter plot and trend line to demonstrate correlation between automatic imitation effect (ms) and autism severity (SRS *t*-score).

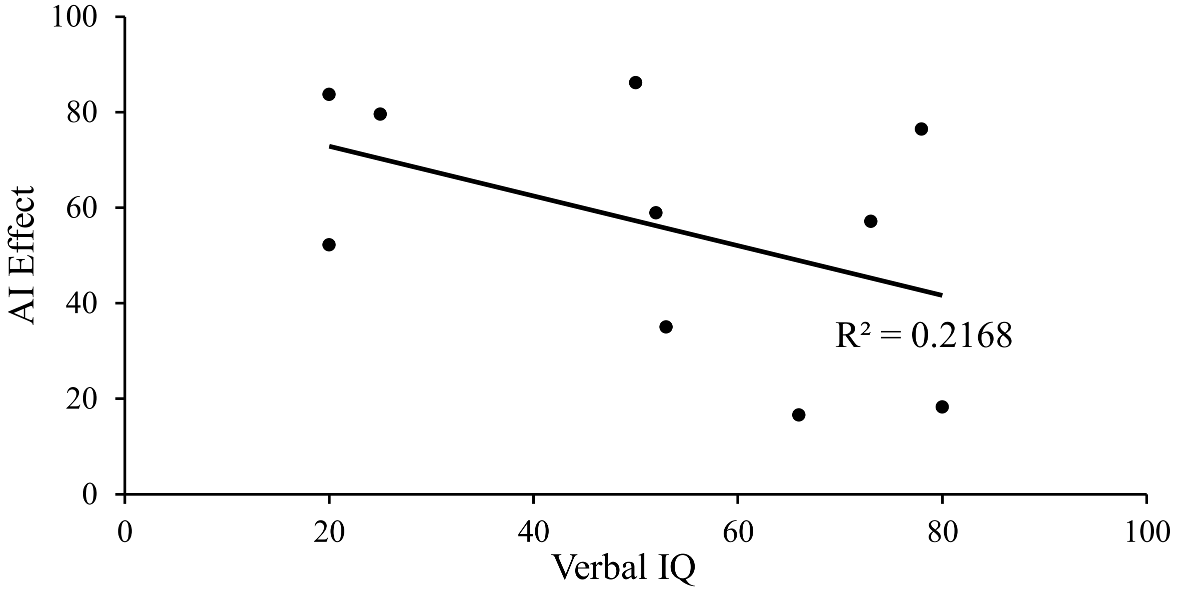

Figure 5. Scatter plot and trend line to demonstrate correlation between automatic imitation effect (ms) and Verbal IQ scores (VIQ).

Errors

Group mean number of errors made on the compatible and incompatible trials is presented in Figure 6. There was a significant difference between the number of errors on the compatible and incompatible trials, t (9) = -3.53, $p < 0.01$. The number of errors made on the incompatible trials (8.80 ± 2.48) was far greater than the number of errors on the compatible trials (1.90 ± 0.64), with greater variation in the data for the incompatible trials.

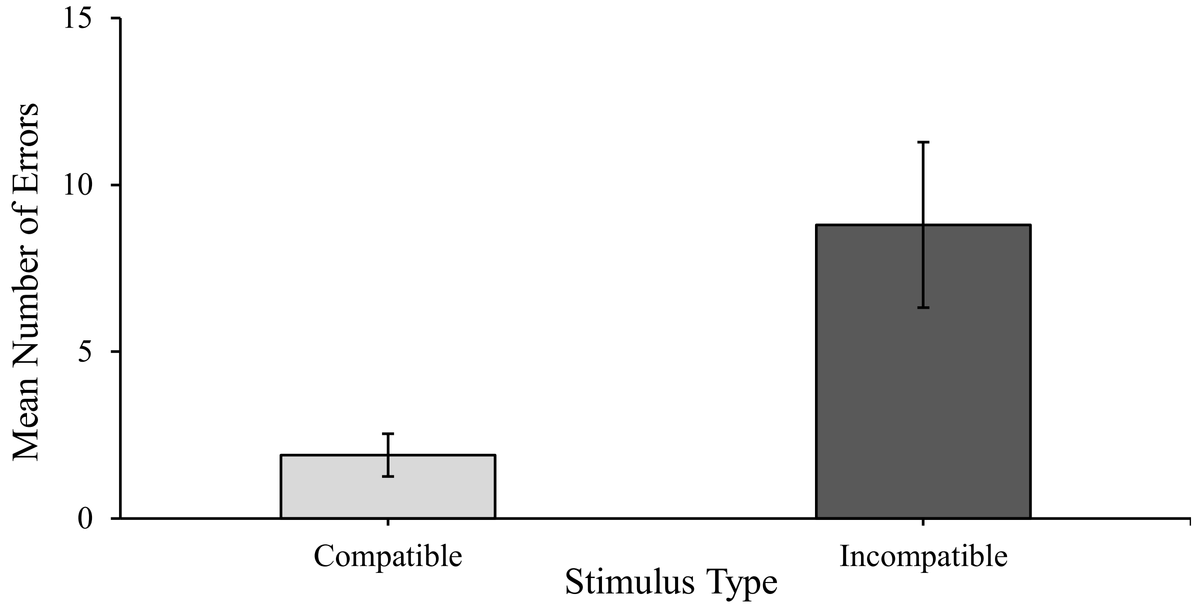

Figure 6. Bar chart to show the mean number of errors participants made on compatible (light grey bar) and incompatible trials (dark grey bar), with standard error of the mean error bars.

Autism Severity Correlations.

As presented in Figure 7, there was no correlation between the number of errors on the compatible trials and SRS *t*-score, $r = -0.12$, $p > 0.05$, or on the incompatible trials and SRS *t*-score, $r = 0.14$, $p > 0.05$. As presented in Figure 8, there was no correlation between the number of errors on the compatible trials and Verbal IQ, $r = -0.13$, $p > 0.05$, or on the incompatible trials and Verbal IQ, $r = -0.47$, $p > 0.05$.

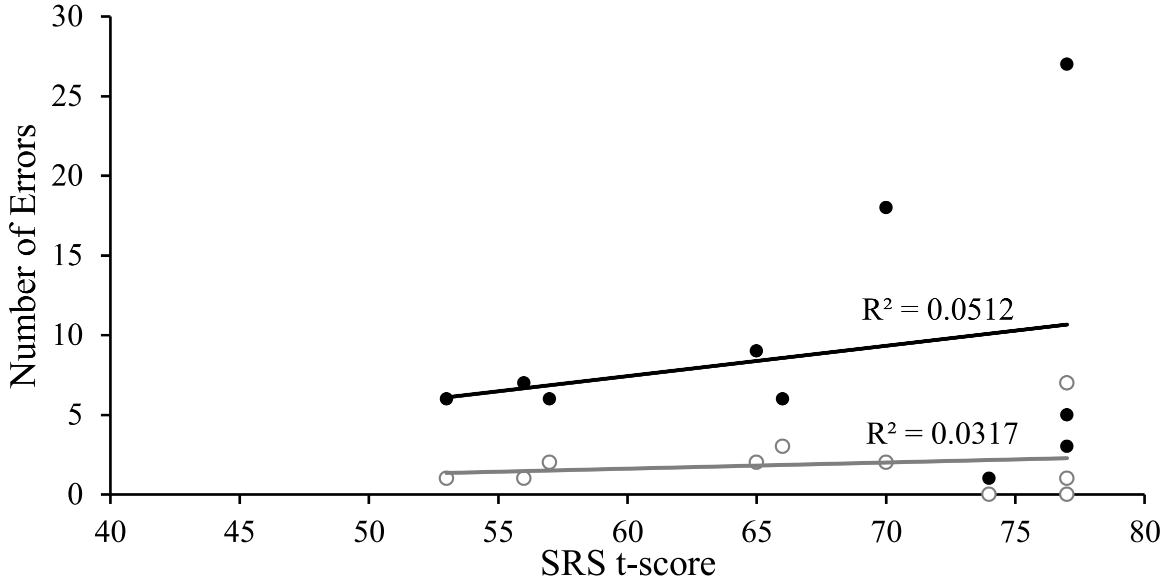

Figure 7. Scatter plot and trend lines to demonstrate correlation between the number of errors on the compatible trials (light grey) and the incompatible trials (black) and SRS t-score.

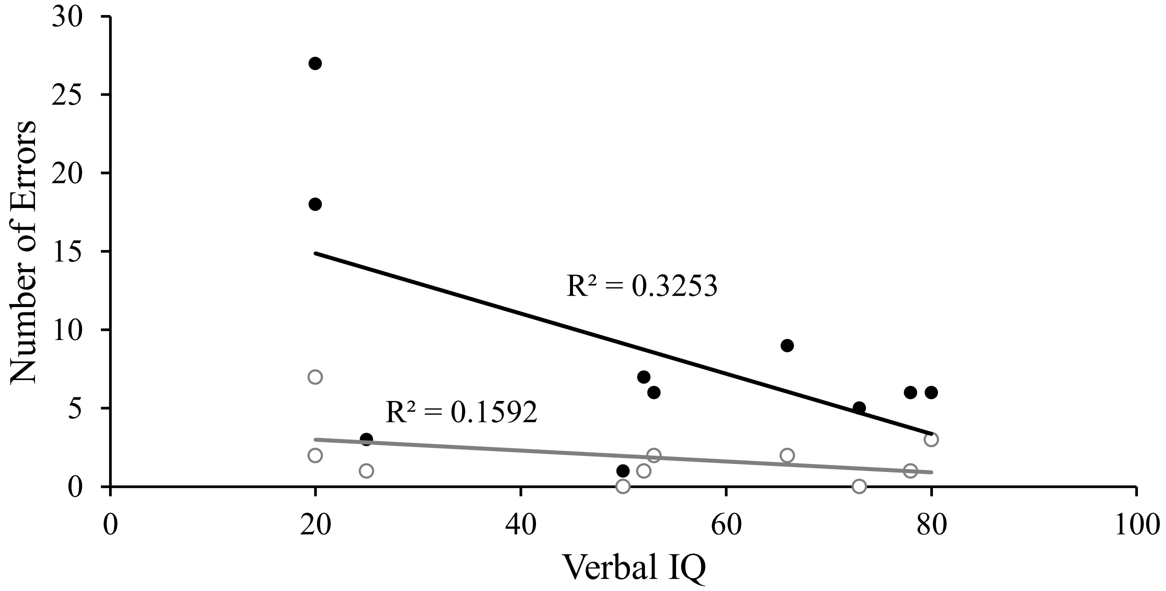

Figure 8. Scatter plot and trend lines to demonstrate correlation between the number of errors on the compatible trials (light grey) and the incompatible trials (black) and *Verbal IQ* scores.

Discussion

Automatic imitation was examined in adults with moderate to severe autism using a finger lifting task with compatible or incompatible video stimuli (Bird et al., 2007; Heyes, 2011; Sowden et al., 2016). Participants exhibited faster reaction times on compatible trials (*M* = 408.29 ± 26.31 ms) than incompatible trials (*M* = 461.65 ± 27.26 ms), and thus an automatic imitation effect of 56.39 ms. This finding is consistent with a previous study of adults with mild autism (Sowden et al., 2016). Interestingly, participants also made more errors on the incompatible trials (*M* = 8.80 ± 2.48) in comparison to the compatible trials (*M* = 1.90 ± 0.64). As will be discussed below, the implication is that the sensorimotor system is functional in adults with moderate to severe autism, due to an intact perception-action link.

In the automatic imitation protocol, the representation of the observed movement interferes with imitation if the trial is incompatible due to a stimulus-response association (Cooper et al., 2013; Herwig et al., 2007; Heyes, 2011; Hommel, Posse, & Waszak, 2000; Sowden et al., 2016). The associative sequence learning model posits that if the observation of an action is dependent on the execution of another action, the visual and motor representations will be associated (Cook et al., 2012b). This association extends to the motor system such that when a stimulus is presented, the sensory system activates the associated aspects of the representation, which then activates the motor system (Hale & Hamilton, 2016; Heyes, 2001, 2011). This produces muscle activation (motor evoked potentials) when this association is triggered by the stimulus (Catmur et al., 2007; Vivanti & Hamilton, 2014). In the current study, this effect was seen in the interference in the incompatible trials, when the incompatible stimulus is seen (i.e. the index finger lifting) this representation is activated in the motor system, which then interferes with the execution of the action required (which would be lifting the middle finger when the index finger was shown), resulting in slower reaction times and more errors for incompatible trials.

The strength of the automatic imitation effect is dependent on the degree to which observed movements interfere with movements being performed (Gowen & Poliakoff, 2012). Frequent exposure (60 trials) strengthens associations between the observed stimulus and the executed action, thereby producing an automatic route (Cooper et al., 2013). This automatic route creates a faster response as it bypasses the comparison between the observed action and representations in the motor system, though this can also produce errors (Brass et al., 2000). The association does not extend to other body parts, so associations between viewing the index finger lifting should not also activate the middle finger lifting association (Heyes et al., 2005; Press, Bird, Walsh, & Heyes, 2008; Wiggett, Hudson, Tipper, & Downing, 2011). However, this does sometimes occur during automatic imitation, which produces the errors seen during the experiment. The speed and/or accuracy of responses is modulated by automaticity and how the stimulus maps onto the required response (Heyes, 2011).

Autistic individuals show intact imitative behaviour, with enhanced automatic imitation associated with higher autism severities, social difficulties, and mentalising differences (Cook & Bird, 2012; Sowden et al., 2016; Spengler et al., 2010). It was said that this relationship between automatic imitation and autism severity is the result of top-down control differences in autism (Shah & Sowden, 2015). Accurate social perception is dependent on bottom-up sensory processing and modulation from top-down processes. Top-down processing involves attention and expectation, with the ability to make predictions based on prior expectations (Cook, Barbalat, & Blakemore, 2012a). The social top-down response modulation (STORM) model (Wang & Hamilton, 2012) suggests that there is a link between action observation and mentalising networks within the brain. To imitate, information derived from action observation is used in the mentalising systems to simulate the movements to aid imitation (Forbes et al., 2017; Wang & Hamilton, 2012). In contrast, if the mentalising systems are used to facilitate social judgments, for example, anticipating others' emotional responses which then facilitates our behavioural response would represent top-down control of the action observation system (Cook et al., 2012a). In the current study, moderate to severely autistic adults show intact imitation, which would mean that from the STORM model (Wang & Hamilton, 2012), their action observation and mentalising networks would be working in tandem (and would also be intact) to mediate the imitation of the observed model. If the action observation and mentalising networks are intact, for the latter studies in this thesis this means that due to a functional perception-action link, there would be expected attentional differences between individuals with moderate to severe autism who have experience of the observed movement compared with those who do not. Therefore, a functioning perception-action link means that the effect of sensorimotor experience on perception can be investigated in a sample of moderate to severely autistic adults.

Motor representations related to the self and other are necessary for imitation and theory of mind (Dapretto et al., 2006; Gallese et al., 1996; Iacoboni, 2009; Sowden & Shah, 2014), wherein information is shared between representations of the self and other when individuals automatically imitate the actions of those they interact with (Brass et al., 2000; Chartrand & Bargh, 1999; Heyes, 2011). When a known action is observed it is matched to the corresponding representation, this representation is then activated, including the motor knowledge of how to execute it (Vivanti & Hamilton, 2014). The relationship between representations and imitation is evidenced in this study in the automatic imitation effect. This means that it can be suggested that the moderate to severely autistic participants in this study show intact imitation, and it can be suggested that from this the sensorimotor system is functional.

Enhanced automatic imitation was not found in the current study, which would be quantified by a correlation between autism severity (i.e. SRS *t*-score) and AI effect. This was possibly due to the severity of the participants compared to previous reports of a hyper-imitation effect in participants who were mildly autistic (Sowden et al., 2016; Spengler et al., 2010). Individuals with mild autism will have relatively less social, sensory, and motor difficulties compared to individuals with severe autism, and therefore the extent to which their imitation is inhibited results in a hyper-imitation effect. The participants in the current study would also have difficulties inhibiting imitation, as would be expected from echolalia and echopraxia, but the physical demands of the protocol may lessen the hyper-imitation effect in the moderate to severe autistic population.

Previously, when difficulties were found in voluntary and automatic imitation in autism, it was thought that it stemmed from a motor processing problem, exhibited by autistic individuals in a harsher styled movement in comparison to the movement of typical controls (Freitag, Kleser, Schneider, & von Gontard, 2007; Hobson & Lee, 1998; McIntosh et al., 2006; Vanvuchelen et al., 2011). The movement and goal required are both simple in this protocol, and therefore a harsher style of movement, should it exist, would not be expected to impact upon the results. The simplicity of the protocol is of importance for the moderate to severe autism population as any automatic imitation occurred unintentionally (Bird et al., 2007; Boyer, Longo, & Bertenthal, 2012; Ekman, 1992; Matsumoto & Lee, 1993). Previous studies (Cook et al., 2010; McIntosh et al., 2006; Sebanz, Knoblich, Stumpf, & Prinz, 2005) utilising joint action tasks or facial expressions would be inaccessible to this population, which could mean that their task performance would be poor even if their ability to imitate was intact (cf. Broken Mirror Theory of autism; Ramachandran & Oberman, 2006). However, automatic imitation provides a robust measure of imitative performance in the moderate to severe autistic population, which here was consistent with intact sensorimotor integration in moderate to severely autistic adults.

Summary

The findings of this chapter confirm that there is an automatic imitation effect in moderate to severely autistic adults, such that compatible trials produced quicker reaction times and fewer errors than incompatible trials. The use of motor representations for imitation in this protocol, and the interference effects seen in the incompatible trials, demonstrates intact imitation in this population. From this it can be suggested that the sensorimotor system is functional in these moderate to severely autistic adults. This is important for subsequent studies in that the development and functioning of the sensorimotor system should extend to other more complex and skilled movements, which can then the effect of sensorimotor experience on perception can be examined.

Chapter Four: Experience Dependent Preferential Viewing in Autistic Adults

Abstract

Individuals who are experienced in an action show greater activation in their action observation system than those who have less or no experience of it (Aglioti et al., 2008; Calvo-Merino et al., 2005; Calvo-Merino et al., 2006). This is due to the experienced individuals having representations in their motor system for the observed action (Iacoboni & Mazziotta, 2007; Mostofsky & Ewen, 2011). In autistic individuals, this activation is thought to not occur (Oberman et al., 2005). When the trampolining group, who have the sensorimotor experience of all of the actions, are compared to the non-trampolining group, who do not have experience of the trampolining actions, they have opposite viewing patterns when viewing trampolining actions, evidenced by *First Fixation Duration* and *First Fixation Location* on Twists, which was the highest skilled level trampolining action demonstrated by the point-light displays. The trampolining group's attention was first drawn to the incongruent model in their *First Fixation Location* but evaluated the congruent model for longer in their *First Fixation Duration*. Whereas the non-trampolining group attended to the congruent model first in their *First Fixation Location* and evaluated the incongruent model for longer in their *First Fixation Duration*. However, there were no significant differences in *Percentage of Total Fixation Duration* on any actions, meaning the effect of sensorimotor experience does not extend past the first fixation. There were also no significant differences between the groups in any dependent variable for Seatdrops, Straight Jumps, or Gait, this means that for the less skilled actions and the actions which both groups have sensorimotor experience of, there were no differences found in how the groups attended to the congruent and incongruent models. From this, it is suggested that sensorimotor development, and functionality, in autism, is intact. This is inferred from the differences found in preferential attention dependent on experience of the observed actions.

Introduction

Although not considered a core characteristic of autism, approximately 80% of autistic individuals demonstrate sensorimotor difficulties during everyday life (Green et al., 2009). These difficulties influence the development of fundamental movement skills (e.g., stability; locomotion; object control) that are important for physical and social development, and as such can impact health and well-being (Dawson, 2008; Vivanti & Hamilton, 2014; Vivanti et al., 2017; Vivanti et al., 2018). In addition to fundamental movement skills, sensorimotor processing differences in autism can impact the acquisition of novel ontogenetic sensorimotor skills (Hannant et al., 2016b). Such sensorimotor behaviours (e.g., sign language; riding a bicycle) are acquired during physical practice and/or training where sensory and motor information are processed and integrated leading to the representation of internal action models (Elliott et al., 2010; Wolpert et al., 2011). This involves the motor system controlling the eyes to orientate the fovea towards sensory information that is relevant to the action, when an action is being learnt, this information is then coupled with the representation (Wolpert et al., 2011).

During the execution of an action, a motor command is are generated during planning as well as an efference copy, which is used to predict the sensory consequences of the action based on sensory information from the environment. Sensory information is used to optimise performance by predicting (using previous experience) and reacting (updating motor commands) (Wolpert et al., 2011). For example, when lifting a teapot, it can be empty or full, with an empty teapot needing less force to lift it than a full one, sensory information from the environment is used to predict if the teapot is full. The prediction is compared with feedback from tactile afferents; if the teapot lifts easily then it is empty (Wolpert & Flanagan, 2001). If there is a mismatch between the predicted and sensory information, the sensorimotor system reacts by updating the internal action model (Wolpert et al., 2011). Following sensorimotor learning, internal action models form part of a mechanism that controls sensorimotor goal-directed behaviour, further learning, and decision-making within complex environments (Centelles et al., 2013; Fan et al., 2010; Hamilton, 2013).

Sensory information associated with known actions activates internal action models in the motor system (Haswell, Izawa, Dowell, Mostofsky, & Shadmehr, 2009; Herwig et al., 2007). Expert pianists (Haueisen & Knösche, 2001), and beginners (Bangert & Altenmüller, 2003) have activation in related areas of the motor cortex when they listen to melodies they can play. Observing another person perform a physically practised action activates brain regions used to perform the action as the representation is retrieved, even though the action is not being executed (Calvo-Merino et al., 2005; Wilson & Knoblich, 2005). Actions that we have no prior experience, and therefore there is no representation to be retrieved, do not produce this activation (Kirsch & Cross, 2015). For actions with no prior experience, individuals with autistic-like traits (measured by the Autism Quotient) have reduced adaption of gaze (search rate: the number of fixations divided by the average fixation duration) to unknown and unpredictable movements, however, individuals with autistic-like traits did not differ in prediction or sensorimotor control (Material-Weight Illusion; heavy looking items are perceived as feeling lighter and are lifted with greater initial force than lighter looking items of the same mass, measured by force and kinematic data) (Arthur, Vine, Brosnan, & Buckingham, 2019). Therefore, Arthur et al. (2019) found that there were no abnormalities in top-down control of action in individuals with autistic-like traits, corresponding with research suggesting there are prediction-dependent capabilities in autistic individuals similar to that of typical individuals (Ego et al., 2016; Gidley Larson & Mostofsky, 2008; Vannuscorps & Caramazza, 2017). For the STORM model (Wang & Hamilton, 2012), this means that if top-down control is intact, then the link between action observation and mentalising networks would be intact, and information derived from action observation would be used in the mentalising systems to simulate the movements (Forbes et al., 2017; Wang & Hamilton, 2012).

Autistic individuals use visual information less than proprioceptive information, the association of the proprioceptive feedback with motor commands is stronger in autism than in typical individuals (Mostofsky & Ewen, 2011). Suggesting there is a unique autism sensory input due to variability in motor execution (Gowen & Hamilton, 2013). This leads to difficulties in orientating towards the goal in motor planning, 78% of autistic participants did not reach the goal of a motor action, thought to be due to significant motor differences between autistic and typical participants (Vernazza-Martin et al., 2005). This difficulty in motor planning and changing already learned movements is referred to as a problem in sensorimotor integration, as the ability to execute a learned movement is intact in autism (Nazarali et al., 2009; Rinehart et al., 2006).

Potential differences in sensorimotor learning and action model formation in autism could explain social difficulties in autism, if the association between visual feedback is weaker, less information will be taken in from the social interaction in autistic individuals (Hannant et al., 2016b). Exacerbated by predictive impairments, events may occur unexpectedly and without cause to autistic individuals, because there is difficulty processing and representing such stimuli. In addition, motor coordination difficulties affect the capability to recognise emotions and attribute these to others, which can then be used to understand feelings and predict behaviours (Baron-Cohen, 2001, 2005; Baron-Cohen & Belmonte, 2005; Baron-Cohen et al., 1985; Cummins et al., 2005; Vivanti & Rogers, 2011). This can be overwhelming and compromise the ability to effectively interact (Dawson et al., 1998; Sinha et al., 2014).

Inflexible behaviour and extreme difficulty in coping with change is associated with autism (Lecavalier, 2005). Generally, autistic individuals requiring the most support have learning difficulties, little or no language, exhibit self-injurious behaviours, memory impairments, and epilepsy (Dawson, 2008; Falck-Ytter, 2015; Falck-Ytter et al., 2013; Riby & Hancock, 2009). Resulting in relatively little research examining the severe end of the spectrum (Lecavalier, 2005; Shattuck et al., 2007). Therefore, little is known about sensorimotor functionality following experience in individuals with autism into adulthood. Due to this, the influence of experience on sensorimotor development and functionality was investigated in adults with autism. A preferential viewing protocol was used to compare gaze behaviour of a group of autistic adults with and without trampolining experience. Participants observed point-light displays of control or experienced movements. Preferential attention was quantified using *First Fixation Location*, *First Fixation Duration,* and *Percentage of Total Fixation Duration*. By quantifying eye movements, the aim is to determine if preferential attention in autism changes as a function of sensorimotor experience. Previous research (Aglioti et al., 2008; Calvo-Merino et al., 2006; Klin et al., 2009) suggests that first fixations will be longer on the experienced stimuli for the trampolining group, who have the experience of the actions, than for the non-trampolining group.

Method

Participants

The original sample of 53 participants was comprised of 12 females, with an age range of 20-59 years (*M* = 36.08, *SD* = 11.96), and 41 males with an age range of 18-60 years (*M* = 33.66, *SD* = 12.05). This was an opportunity sample, recruited from a trampolining centre that ran as part of the AutismAbility project and the Social Enterprise at Bromborough Pool Village at Autism Together. However, 12 participants were removed from the study due to issues with attention span and/or behavioural problems (such as turning off equipment, leaving during collection, or not looking at the screen), poor data quality, and their hours of trampolining experience (i.e., some experience but less than 100 hrs: 100 hrs being classed as having expertise by Ericsson, Krampe, and Tesch-Römer (1993)). This left a total of 41 participants, of which there were 12 females, with an age range of 20-59 years (*M* = 36.08, *SD* = 11.96), and 41 males with an age range of 18-60 years (*M* = 33.66, *SD* = 12.05). These were allocated to two groups according to their trampolining experience. The trampolining group (n = 22) with an average of 144 hours of experience (see Table 16 for individuals' hours of experience), consisted of 4 females, with an age range of 20-59 years (*M* = 38.75, *SD* = 16.46), and 18 males with an age range of 22-52 years (*M*= 32.83, *SD*= 10.26). The non-trampolining group (n = 19) consisted of 4 females, with an age range of 29-43 years (*M* = 35.75, *SD* = 5.74), and 15 males with an age range of 18-60 years (*M* = 38.80, *SD* = 14.57). Participants had normal or corrected-to-normal vision and were screened via their person-centred plans for the following exclusion criteria: dyspraxia, dyslexia, epilepsy, and other neurological or psychiatric conditions, sample characteristics are presented in Table 17.

Participants were approached by the researcher, their support worker, or the group lead to establish their willingness to participate. The researchers were clear that the personal interests of the participants were of utmost importance, with all invited participants allowed as much time as necessary to make a decision regarding their involvement in the study. Where possible, consent was obtained from the participants. However, in certain cases it was necessary to refer to the Mental Capacity Act (2005) to establish a participant's capacity to make a decision. One-to-one support workers, group leads, and activity leaders facilitated this process. Once capacity to consent to participate in the study was established, all necessary measures were completed for each participant before starting the protocol. The experiment was approved by the Liverpool John Moores University ethics committee.

Table 16. *Number of hours of experience trampolining retrospectively calculated for each participant in the trampolining group.*

Participant	**Experience (hours)**
1	176
2	176
3	176
4	150
5	176
6	124
7	124
8	158
9	125
10	121
11	114
12	124
13	127
14	181
15	128
16	128
17	128
18	127
19	119
20	127
21	184
22	184

Table 17. *Participant Demographics.*

		Trampolining Group Mean (SD)	Non-trampolining Group Mean (SD)
n		22	19
	Gender	4 females	4 females
VIQ		44 (22)	48 (28)
	Age Equivalent	6 years 5 months	7 years 6 months
SRS	*t*-score	72 (10)	65 (12)
	AWR	67 (13)	65 (13)
	COG	74 (9)	67 (14)
	COM	71 (10)	65 (13)
	MOT	64 (11)	59 (12)
	SCI	71 (10)	66 (13)
	RRB	75 (8)	66 (12)
SP	Seeking	40 (12)	27 (11)
	Avoiding	54 (11)	44 (13)
	Sensitivity	46 (10)	36 (12)
	Registration	48 (11)	39 (16)
	Auditory	23 (5)	18 (7)
	Visual	15 (4)	7 (5)
	Touch	24 (6)	14 (6)
	Movement	17 (6)	13 (6)
	Body Position	12 (4)	13 (7)
	Oral	17 (7)	15 (9)
	Conduct	20 (5)	17 (6)
	Social Emotional	41 (9)	34 (10)
	Attentional	27 (7)	23 (8)
MABC	Total Test	6 (5)	7 (6)
	Manual Dexterity	9 (7)	11 (7)
	Aiming & Catching	8 (6)	8 (5)
	Balance	4 (3)	5 (4)

VIQ – Verbal IQ, measured by the Peabody Picture Vocabulary Test (fourth edition)

SRS – Social Responsiveness Scale (second edition)

SP – Sensory Profile (second edition)

MABC – Movement Assessment Battery for Children (second edition).

Stimuli

Point-light displays were generated that depicted an autistic individual (model) performing either gait or three trampolining actions (Twists, Seatdrops, and Straight Jumps). Straight Jumps and Gait were expected to be familiar to the trampolining and non-trampolining groups. Twists and Seatdrops were defined as skilled action stimuli because only the trampolining group would have gained sensorimotor experience of performing these more complex trampolining actions.

The autistic individuals performing these actions were fitted with 38 retroflective markers in the Plug-in-Gait Marker Placement (4 on head, 7 on torso, 9 on arms, 4 on pelvis, 14 on legs and feet) and filmed using the Vicon Bonita (Vicon Motion Systems Ltd., 2012) at a sampling rate of 100 Hz. The resulting data was processed in Vicon Nexus, which allowed manual identification of missing markers using a gap filling procedure. The x-y-z time-series data was the exported to Visual 3D, which allowed an animation of the moving markers (i.e., point-light display) to be saved as a video in AVI format (50 fps and 1280 x 720 pixel resolution). This AVI was then imported to iMovie, where a split screen (i.e., preferential viewing) was created. Tobii Studio was used to present the point-light display stimuli while simultaneously recording movement of both eyes at 60 Hz with the Tobii x2-60 screen-based eye-tracking system (tobii pro, 2018a). An advantage of this system over other desktop-mounted eye-tracking systems is that it can tolerate large and fast head movements, which is necessary for participants who have repetitive and stereotyped behaviours such as rocking (i.e., a criterion for a diagnosis of autism spectrum disorder). Data validity (gaze sample percentage) range from 21-99 in the trampolining group (M = 65.18), and 20-90 in the non-trampolining group (M = 56.67).

Two point-light displays were displayed in a preferential viewing protocol where attention towards each point-light display can be compared. The point-light displays demonstrated the same action, but one side of the screen showed, for example, Straight Jumps in the upright position (congruent) and on the other showed Straight Jumps in inverted orientation rotated through 180 degrees (incongruent) (see Figure 9).

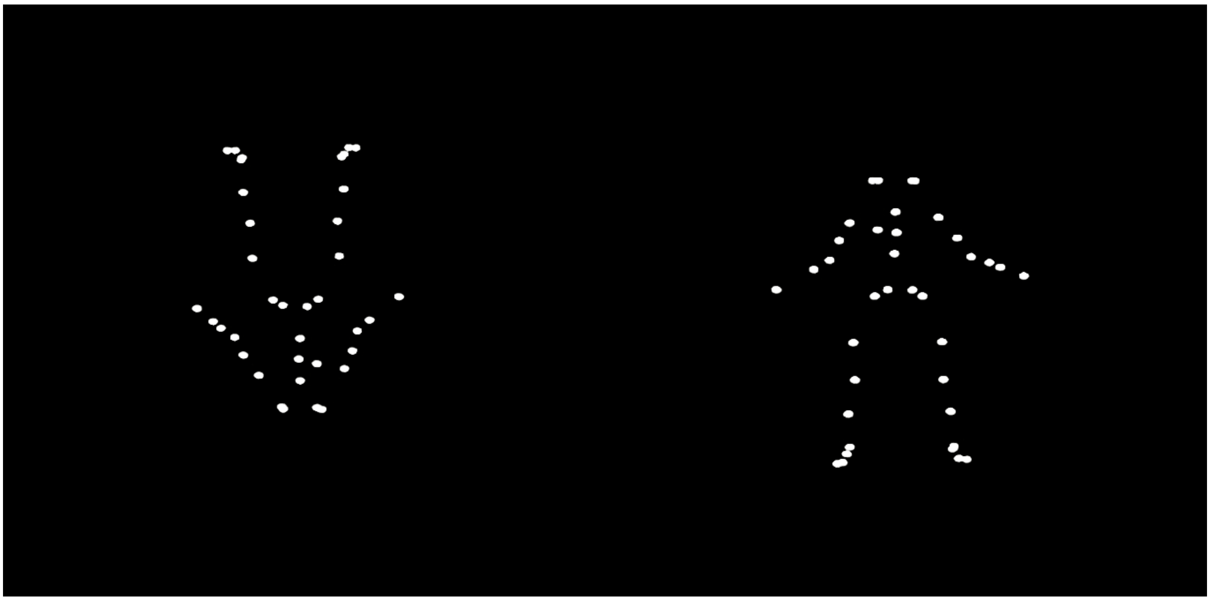

Figure 9. Point-light displays used for Preferential Viewing, autistic model in the congruent (right) and incongruent (left) orientation.

Design

Three dependent variables were quantified to measure preferential attention (*First Fixation Location*) and visual processing (*First Fixation Duration*, and *Percentage of Total Fixation Duration*). A fixation was defined as an eye movement 100 milliseconds or longer in duration, moving with a velocity of less than 30 degrees/second (filtered using the Tobii I-VT filter) (tobii pro, 2018b).

First Fixation Location quantified the earliest time to record (in milliseconds) that a fixation located on a congruent or incongruent spatial location (i.e., area of interest), over the four trials for each action (Twists, Seatdrops, Straight Jumps, Gait). This was expressed as categorical, binary data for the first trial that the participant fixated on, either congruent or incongruent. *First Fixation Location* data for the first trial was submitted to a Chi Square test of independence, this was because the data was categorical and binary, so therefore it is not normally distributed. The Chi Square test of independence measures whether there was a difference between the observed finding, and what would be expected if there was no difference between the variables (i.e. the null hypothesis), for this data it would be assumed that 50% of the groups would have a *First Fixation Location* on the congruent side and the other 50% of the group would have a *First Fixation Location* on the incongruent side. If the observed data significantly differs from the 50% then it is a significant difference.

First Fixation Location was also analysed over the course of the trials, the binary data for each trial (congruent or incongruent) was used to calculate the overall percentage that the participant fixated first on the congruent or incongruent. For example, if the participant fixated first on the congruent side for 3 trials and the incongruent side for 1 trial, then the participant fixated on the congruent side for 75% of the experiment (3 / (3+1)). These variations were used to see where the participants initial attention was drawn, but then how this changed after viewing the stimuli multiple times.

First Fixation Duration was defined as the duration in milliseconds of the first fixation made on the area of interest. *Percentage of Total Fixation Duration* was defined as the sum of the durations of all fixations made within an area of interest, divided by the sum of the fixation durations made on both areas of interest. For example, if the congruent side had a total fixation duration of 300 milliseconds, and the incongruent side had a total fixation duration of 700 milliseconds, then the participant will have fixated on the congruent side for 30% of the trial (300 / (300+700)). This follows on from work by Klin (Jones et al., 2008; Klin & Jones, 2008; Klin et al., 2003; Klin et al., 2002; Klin et al., 2009) in which *Percentage of Total Fixation Duration* was used to quantify preferential attention to different areas of interest. Arcsine square root transformation was performed on the percentage data to account for the fact that proportional data is not normally distributed and over dispersed (Ahrens, Cox, & Budhwar, 1990; Warton & Hui, 2011).

Procedure

Participants were given the simple instruction to watch the videos and were not given details about what they were going to be watching, thus minimizing any unintentional experimenter influence on gaze behaviour. However, to ensure that the participant engaged in the task and followed the simple instruction, the experimenter sat at a right angle to the participant in front of a laptop that controlled the stimulus presentation and eye-tracking software (see Figure 10). Participants sat 45-100cm from a 20-inch LCD screen (1600 x 900 resolution, 75Hz refresh rate), which acted as the external screen below which the eye-tracker was mounted. Participants were asked to stay seated and told they could move in the seat once calibration was complete. To minimise calibration duration and avoid calibration errors in those with repetitive behaviours such as rocking, a 2-point calibration template was used.

Participants watched 16 trials, arranged in a 4 x 4 blocked design. The four actions (Twists, Seatdrops, Straight Jumps, and Gait) were repeated four times in a single block, with the 4 blocks received in a pseudo-randomised order, similar to work by Klin et al. (2009) and Roché et al. (2013). At the start of a trial, a fixation cross appeared in the centre of the screen for 2 seconds, then the point-light display was shown on screen for 8 seconds. This was to centre the participants gaze to a neutral position before presenting the point-light stimuli on each side of the screen, which gave the experimenter an opportunity to redirect participants attention back to the experiment if and when they lost concentration. The total experiment time was 4 minutes.

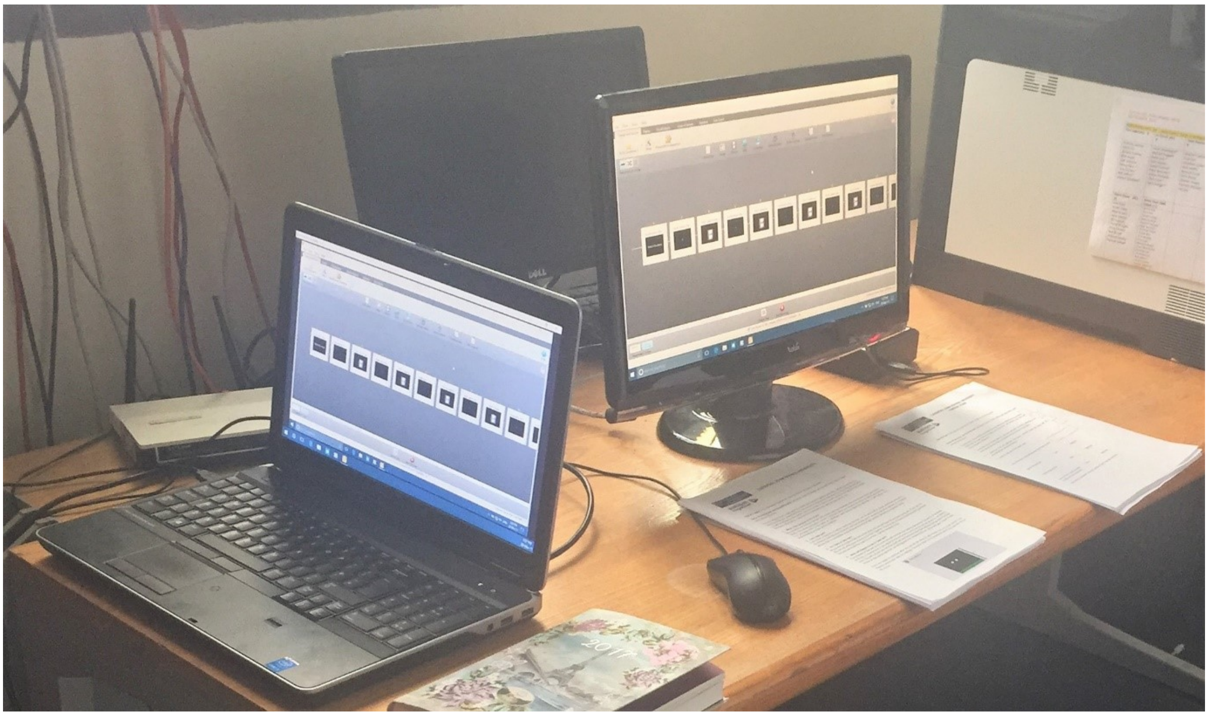

Figure 10. Set up of eye-tracking system at a right-angle for the Preferential Viewing Protocol.

Data analysis

First Fixation Duration and *Percentage of Total Fixation Duration* was calculated for the first trial that the participant fixated for, and also as intra-participant mean data, calculated over the four trials for each action (Twists, Seatdrops, Straight Jumps, Gait), with a minimum of two trials was used for the data across the trials. *Percentage of First Fixation Location, First Fixation Duration,* and *Percentage of Total Fixation Duration* for each action were submitted to separate 2 Group (trampolining; non-trampolining group) x 2 Congruency (congruent; incongruent) mixed factor ANOVAs. Alpha was set at $p < 0.05$, and partial eta-squared (η_p^2) expressed the size of the effect. Significant interactions effects were decomposed using the multiple *t*-tests for which Type I error was control (Alpha was set to $p < 0.01$).

A correlational analysis (Pearson's *r* and Point-Biserial) was used to determine if measures of gaze behaviour (*First Fixation Location, Percentage of First Fixation Location,* *First Fixation Duration,* and *Percentage of Total Fixation Duration)* were independent of the autism severity or motor proficiency (*SRS-2 t*-score and *MABC-2* standardised total test score) where there were differences between the groups.

Results

First Fixation Location

First Trial.

Data for observed and expected frequency scores are presented in Table 18. For Twists, there was a significant difference between observed and expected frequencies [χ^2 (1) = 3.77, $p < 0.05$] that indicated significantly more participants from the trampolining group fixated first on the incongruent model (10 participants) compared to the congruent model (3 participants). Whereas there was no significant difference between observed and expected frequencies [χ^2 (1) = 1.67, $p > 0.05$] for the non-trampolining group. Pearson's correlation coefficients can be found in Table 19, there are no significant correlations between SRS *t*-score and MABC standardised score with *First Fixation Location* for Twists.

Chi-squared analyses revealed no further significant differences between observed and expected frequencies for Seatdrops [trampolining group, χ^2 (1) = 1.14, $p > 0.05$; non-trampolining, χ^2 (1) = 3.00, $p > 0.05$], Straight Jumps [trampolining group, χ^2 (1) = 0.00, $p > 0.05$; non-trampolining group, χ^2 (1) = 3.00, $p > 0.05$], or Gait [trampolining group, χ^2 (1) = 1.00, $p > 0.05$; non-trampolining group, χ^2 (1) = 0.25, $p > 0.05$].

Table 18. *Pearson correlation matrix for demographics and First Fixation Location for Twists.*

	Trampolining Group	Non-trampolining Group
SRS	-0.23	-0.40
MABC	0.41	0.22

* $p < 0.05$

Four Trials.

ANOVAs revealed no significant effects for Twists [congruency, F (1, 17) = 0.75, $p >$ 0.05, $\eta p^2 = 0.04$; group, F (1, 17) = 1.95, $p > 0.05$, $\eta p^2 = 0.10$; group x congruency interaction, F (1, 17) = 0.27, $p > 0.05$, $\eta p^2 = 0.02$], Seatdrops [congruency, F (1, 18) = 0.71, $p > 0.05$, $\eta p^2 = 0.04$; group, F (1, 18) = 0.004, $p > 0.05$, $\eta p^2 = 0.00$; interaction, F (1, 18) = 0.04, $p > 0.05$, $\eta p^2 = 0.00$], Straight Jumps [congruency, F (1, 16) = 0.04, $p > 0.05$, $\eta p^2 = 0.00$; group, F (1, 16) = 2.03, $p > 0.05$, $\eta p^2 = 0.11$; group x congruency interaction, F (1, 16) = 0.50, $p > 0.05$, $\eta p^2 = 0.03$], and Gait [congruency, F (1, 19) = 1.87, $p > 0.05$, $\eta p^2 = 0.09$; group, F (1, 19) = 0.03, $p > 0.05$, $\eta p^2 = 0.00$; group x congruency interaction, F (1, 19) = 0.92, $p > 0.05$, $\eta p^2 = 0.05$]. As illustrated in Figure 11, the findings indicate that there were no significant differences between the trampolining and non-trampolining groups in the spatial location of the first fixation on the congruent or incongruent models.

Table 19. *Frequencies of observed and expected values for the two groups (trampolining and non-trampolining) on the two models (congruent and incongruent) for First Fixation Location for the four actions (Twists, Seatdrops, Straight Jumps, Gait).*

		Congruent	**Incongruent**	**Expected**	**Residual**	**Significance**
Twists	Trampolining	3	10	6.5	3.5	0.05 *
	Non-trampolining	10	5	7.5	2.5	0.20
Seatdrops	Trampolining	9	5	7	2	0.29
	Non-trampolining	9	3	6	3	0.08
Straight Jumps	Trampolining	6	6	6	0	1.00
	Non-trampolining	9	3	6	3	0.83
Gait	Trampolining	10	6	8	2	0.32
	Non-trampolining	9	7	8	1	0.62

* $p < 0.05$

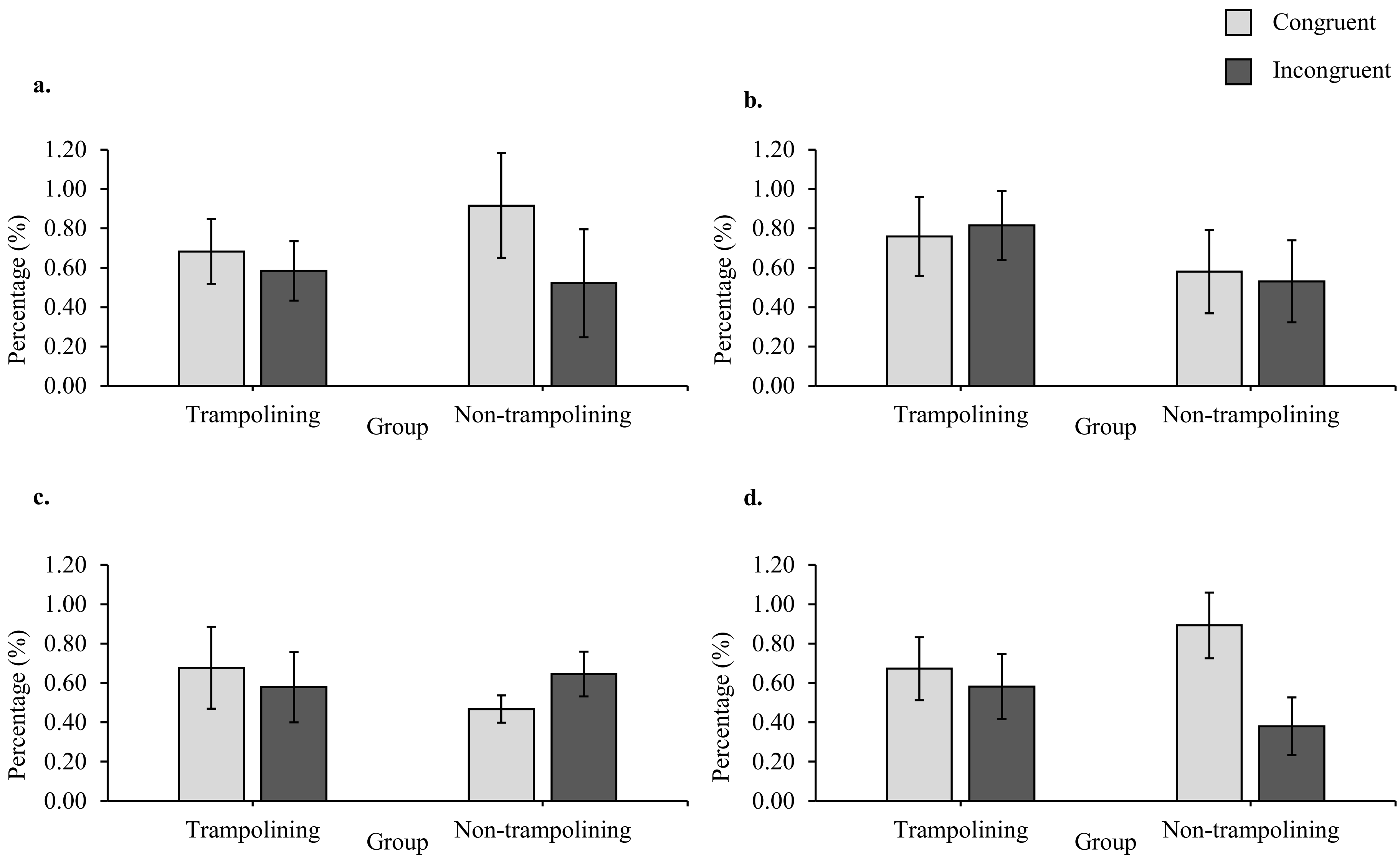

Figure 11. First Fixation Location across the trials for Twists (a), Seatdrops (b), Straight Jumps (c), and Gait (d) on the congruent (light grey bars) and the incongruent (dark grey) models, with standard error of the mean (error bars).

First Fixation Duration

First Trial.

ANOVAs revealed no significant effects for Twists [congruency, F (1, 23) = 1.41, $p >$ 0.05, $\eta p^2 = 0.06$; group, F (1, 23) = 0.28, $p > 0.05$, $\eta p^2 = 0.01$; congruency x group interaction, F (1, 23) = 1.38, $p > 0.05$, $\eta p^2 = 0.06$], Seatdrops [congruency, F (1, 24) = 0.06, $p > 0.05$, $\eta p^2 = 0.00$; group, F (1, 24) = 1.98, $p > 0.05$, $\eta p^2 = 0.08$; congruency x group interaction, F (1, 24) = 0.06, $p > 0.05$, $\eta p^2 = 0.00$], Straight Jumps [congruency, F (1, 21) = 0.13, $p > 0.05$, $\eta p^2 = 0.00$; group, F (1, 21) = 2.81, $p > 0.05$, $\eta p^2 = 0.12$; congruency x group interaction, F (1,21) = 0.00, $p > 0.05$, $\eta p^2 = 0.00$], or Gait [congruency, F (1, 24) = 1.09, $p > 0.05$, $\eta p^2 = 0.04$; group, F (1, 24) = 0.54, $p > 0.05$, $\eta p^2 = 0.02$; congruency x group interaction, F (1,24) = 0.56, $p >$ 0.05, $\eta p^2 = 0.02$]. As displayed in Figure 12, the trampolining and non-trampolining groups demonstrated no significant differences in the duration of the first fixation on the congruent or incongruent model.

Four Trials.

ANOVA revealed no significant main effects for Twists [congruency, F (1, 23) = 1.51, $p > 0.05$, $\eta p^2 = 0.06$; group, F (1, 23) = 0.08, $p > 0.05$, $\eta p^2 = 0.01$], however there was a significant congruency x group interaction [F (1, 23) = 5.23, $p < 0.05$, $\eta p^2 = 0.19$]. Independent-samples t-test revealed no significant differences between the groups when viewing the congruent model [t (31) = 1.14, $p > 0.01$], or the incongruent model [t (27) = -1.47, $p > 0.01$]. As displayed in Figure 13a, and confirmed via paired samples t-tests, the trampolining group fixated for a significantly longer duration [t (12) = 3.23, $p < 0.01$] on the congruent model (196 ms) compared to the incongruent model (145 ms), whereas there was no significant difference in viewing durations [t (11) = -0.62, $p > 0.01$] for the non-trampolining group when viewing the incongruent model (183 ms) and the congruent model (167 ms). Pearson's correlation coefficients can be found in Table 20, there are no significant correlations between SRS *t*-score and MABC standardised score with *and First Fixation Duration* for Twists.

Table 20. *Pearson correlation matrix for demographics and First Fixation Duration for Twists.*

	Trampolining Group		Non-trampolining Group	
	Congruent	Incongruent	Congruent	Incongruent
SRS	-0.21	0.32	-0.07	-0.46
MABC	-0.50	0.16	-0.07	-0.26

* $p < 0.05$

Furthermore, there were no significant effects for Seatdrops [congruency, F (1, 25) = 0.002, $p > 0.05$, $\eta p^2 = 0.00$; group, F (1, 25) = 3.17, $p > 0.05$, $\eta p^2 = 0.11$; congruency x group interaction, F (1, 25) = 3.94, $p > 0.05$, $\eta p^2 = 0.14$] Straight Jumps [congruency, F (1, 25) = 3.45, $p > 0.05$, $\eta p^2 = 0.12$; group, F (1, 25) = 1.00, $p > 0.05$, $\eta p^2 = 0.11$; congruency x group interaction, F (1,25) = 0.14, $p > 0.05$, $\eta p^2 = 0.00$], and Gait [congruency, F (1, 25) = 1.69, $p > 0.05$, $\eta p^2 = 0.06$; group, F (1, 25) = 3.07, $p > 0.05$, $\eta p^2 = 0.11$; congruency x group interaction, F (1,25) = 0.002, $p > 0.05$, $\eta p^2 = 0.01$]. As displayed in Figure 13 (b-d), the trampolining and non-trampolining groups demonstrated no significant difference in the duration of the first fixation on the congruent or incongruent models for the Gait, Straight Jumps, or Seatdrops.

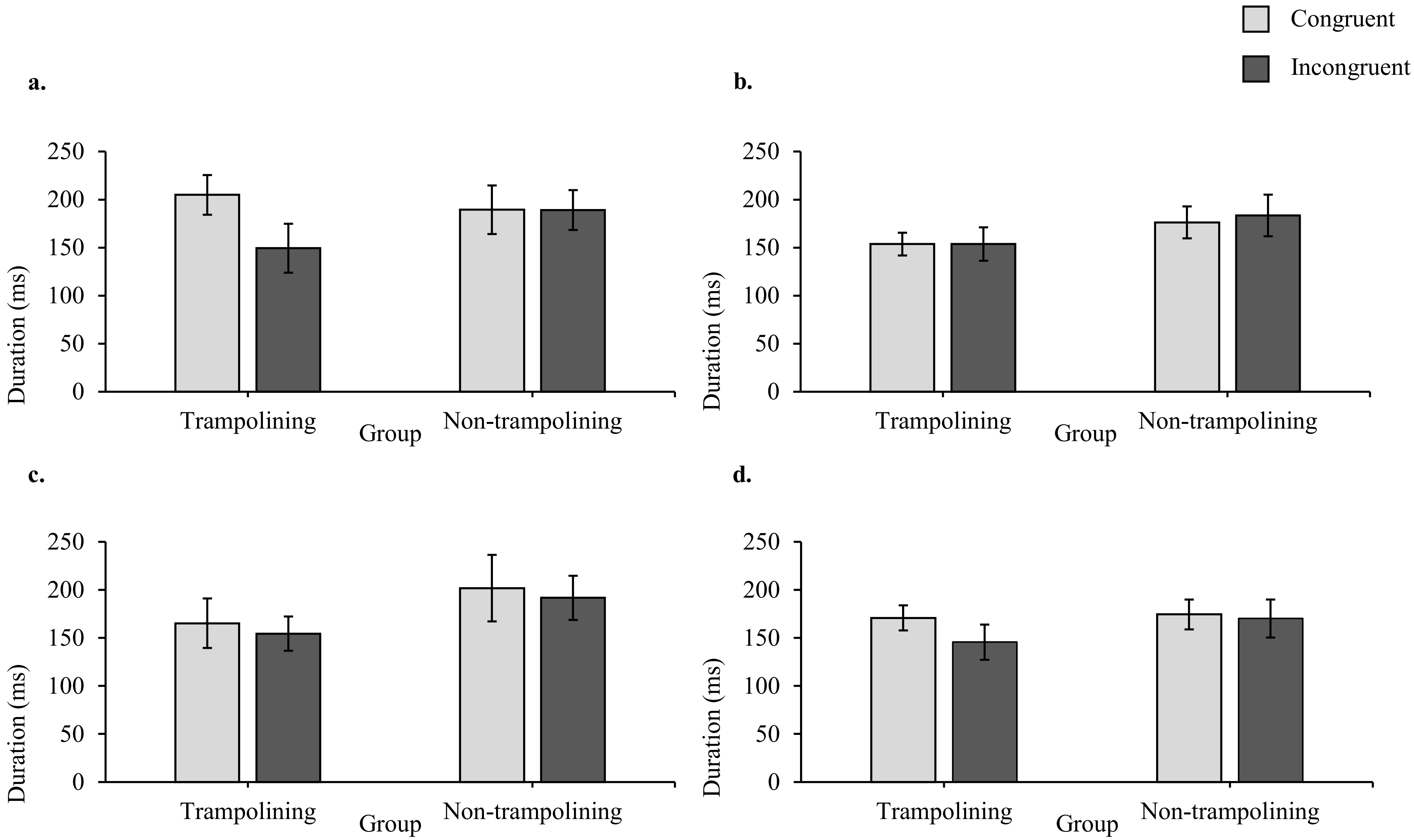

Figure 12. First Fixation Duration on the first trial for Twists (a), Seatdrops (b), Straight Jumps (c), and Gait (d) on the congruent (light grey bars) and the incongruent (dark grey) models, with standard error of the mean (error bars).

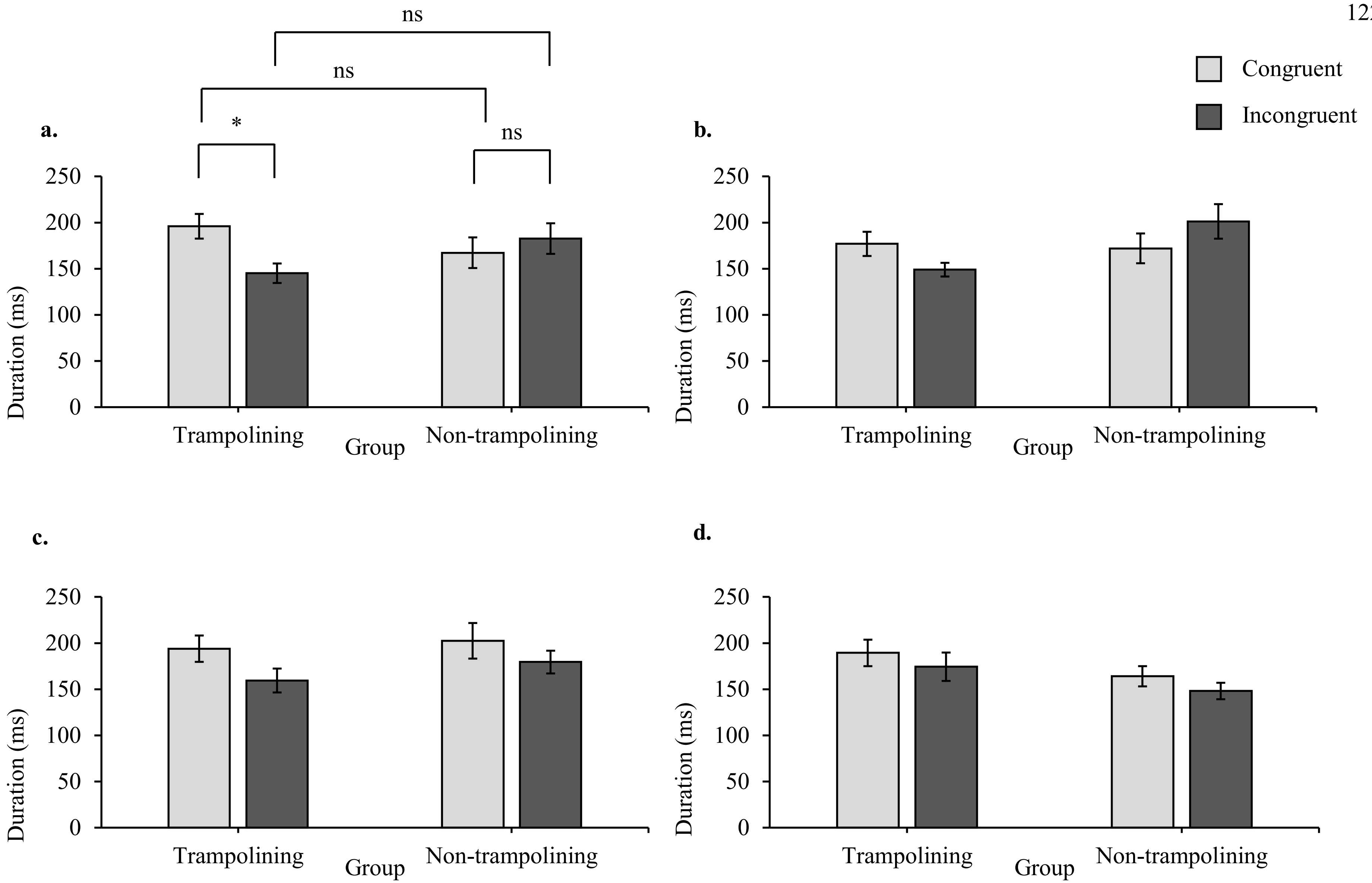

Figure 13. First Fixation Duration across the trials for Twists (a), Seatdrops (b), Straight Jumps (c), and Gait (d) on the congruent (light grey bars) and the incongruent (dark grey) models, with standard error of the mean (error bars).

Percentage of Total Fixation Duration

First Trial.

ANOVA revealed no significant effects for Twists [congruency, F (1, 21) = 0.15, $p >$ 0.05, $\eta p^2 = 0.01$; group, F (1, 21) = 1.06, $p > 0.05$, $\eta p^2 = 0.05$; group x congruency interaction, F (1, 21) = 0.49, $p > 0.05$, $\eta p^2 = 0.02$].

For Seatdrops, whilst there were no significant main effect of congruency (F (1, 24) = 0.84, $p > 0.05$, $\eta p^2 = 0.03$), though there was a significant main effect of group (F (1, 24) = 4.49, $p < 0.05$, $\eta p^2 = 0.16$), and a significant group x congruency interaction (F (1, 24) = 4.99, $p < 0.05$, $\eta p^2 = 0.17$). When Type I errors were controlled for, independent-samples *t*-tests revealed no significant differences between the trampolining and non-trampolining group viewing the congruent model [t (24) = -2.46, $p > 0.01$] or the incongruent model [t (24) = 1.98, $p > 0.01$]. Paired-samples *t*-tests revealed no significant differences when viewing the congruent and incongruent models for the trampolining group [t (12) = -1.19, $p > 0.01$], or for the non-trampolining group [t (12) = 1.89, $p > 0.01$].

ANOVAs revealed no significant effects for Straight Jumps [congruency, F (1, 23) = 0.75, $p > 0.05$, $\eta p^2 = 0.03$; group, F (1, 23) = 1.00, $p > 0.05$, $\eta p^2 = 0.04$; group x congruency interaction F (1,23) = 0.21, $p > 0.05$, $\eta p^2 = 0.00$], or Gait [congruency, F (1, 25) = 2.15, $p >$ 0.05, $\eta p^2 = 0.08$; group, F (1, 25) = 0.50, $p > 0.05$, $\eta p^2 = 0.02$; group x congruency interaction, F (1,25) = 1.18, $p > 0.05$, $\eta p^2 = 0.05$]. As displayed in Figure 14, the trampolining and non-trampolining groups demonstrated no significant difference in the *Percentage of Total Fixation Duration* on the congruent or incongruent models for the Gait, Straight Jumps, Seatdrops, or Twists.

Four Trials.

ANOVAs revealed no significant effects for Twists [congruency, F (1, 24) = 0.32, $p >$ 0.05, $\eta p^2 = 0.01$; group, F (1, 24) = 1.29, $p > 0.05$, $\eta p^2 = 0.00$; group x congruency interaction, F (1, 24) = 0.01, $p > 0.05$, $\eta p^2 = 0.05$], Seatdrops [congruency, F (1, 27) = 0.59, $p > 0.05$, $\eta p^2 = 0.02$; group, F (1, 27) = 0.83 $p > 0.05$, $\eta p^2 = 0.03$; group x congruency interaction F (1, 27) = 0.11, $p > 0.05$, $\eta p^2 = 0.00$], Straight Jumps [congruency, F (1, 26) = 0.52, $p > 0.05$, $\eta p^2 =$ 0.02; group, F (1, 26) = 0.07, $p > 0.05$, $\eta p^2 = 0.02$; group x congruency interaction, F (1, 26) = 3.64, $p > 0.05$, $\eta p^2 = 0.12$] and Gait [congruency, F (1, 28) = 1.02, $p > 0.05$, $\eta p^2 = 0.04$; group, F (1, 28) = 0.03, $p > 0.05$, $\eta p^2 = 0.00$; group x congruency interaction, F (1,28) = 0.32, $p >$ 0.05, $\eta p^2 = 0.01$]. As displayed in Figure 15, the trampolining and non-trampolining groups demonstrated no significant difference in the *Percentage of Total Fixation Duration* on the congruent or incongruent across all actions.

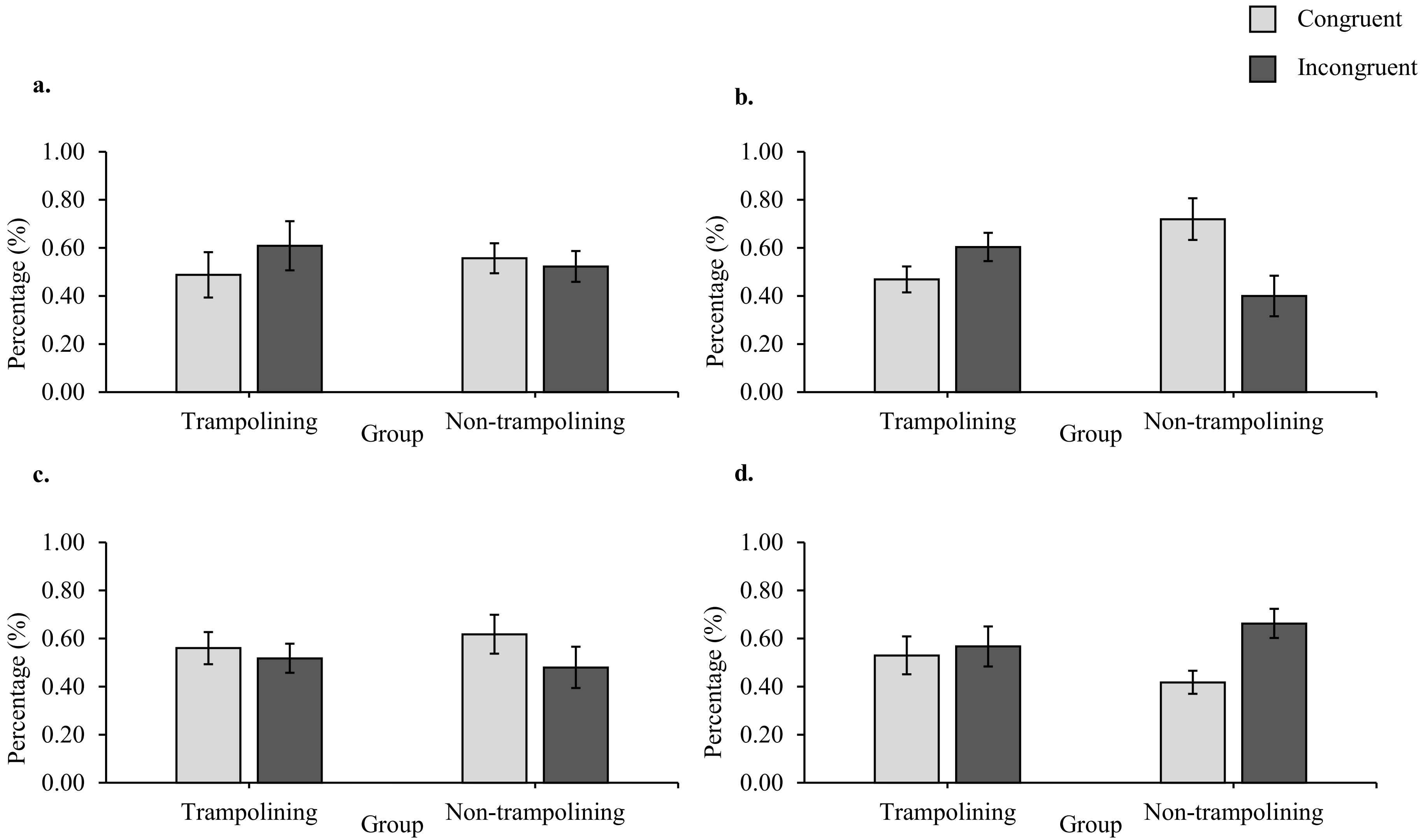

Figure 14. Percentage of Total Fixation Duration on the first trial for Twists (a), Seatdrops (b), Straight Jumps (c), and Gait (d) on the congruent (light grey bars) and the incongruent (dark grey) models, with standard error of the mean (error bars).

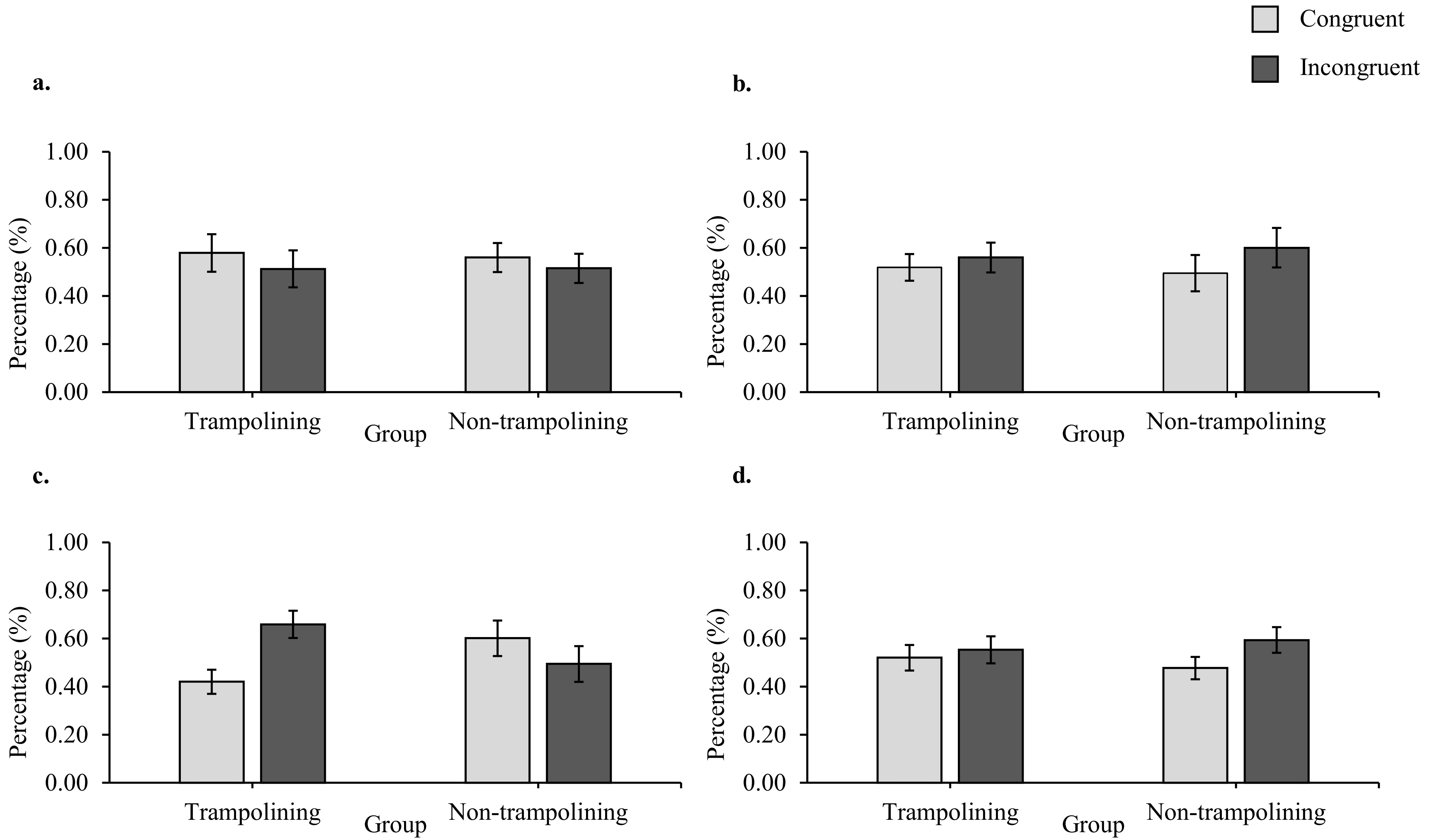

Figure 15. Percentage of Total Fixation Duration across the trials for Twists (a), Seatdrops (b), Straight Jumps (c), and Gait (d) on the congruent (light grey bars) and the incongruent (dark grey) models, with standard error of the mean (error bars).

Discussion

The present chapter examined whether sensorimotor experience underpins task-specific visual perception (e.g., preferential attention; and processing) of experienced/learned movements. To do this, gaze behaviour (i.e., *First Fixation Location*; *Duration*) during preferential viewing was quantified in a group of autistic individuals with, and without. The preferential viewing protocol displayed two movements presented together side-by-side on a split-screen monitor where one movement was congruent (e.g., upright) and one was incongruent (e.g., inverted). The *First Fixation Location* data indicated that both groups of participants orientated attention to the congruent stimuli when observing Gait, Straight Jumps, and Seatdrops, but showed significantly different patterns of gaze behaviour when observing Twists. Here, the trampolining group that had accrued 140 hours of trampolining experience orientated attention to the incongruent model, and the non-trampolining group orientated attention to the congruent model. In terms of duration, the congruency x group interaction for the *First Fixation Duration* across the four trials for Twists indicated the trampolining group fixated for significantly longer on the congruent model (196 ms) compared to the incongruent model (145 ms), whereas the non-trampolining group showed no significant difference in the *First Fixation Duration* when observing the congruent (167 ms) or incongruent (183 ms) models. Finally, there was no significant differences between the groups in any measures of preferential attention when observing the actions that both groups have sensorimotor experience of (Seatdrops, Straight Jumps, and Gait).

The *First Fixation Location* data is important because it indicated that visual attention during preferential viewing was differentiated when the groups observed a model displaying Twists in an incongruent orientation. Unlike Gait, which is a fundamental movement skill (Staples & Reid, 2010), and therefore most likely familiar to both groups, Twists is a specialised action associated with trampolining and more likely to be related to the motor experience developed across practice (~ 140 hours) in the trampolining group. Therefore, the fact that the trampolining group orientated first fixation attention to the incongruent model suggests that the accumulated sensorimotor experience of performing Twists is likely to have underpinned the specificity of preferential attention.

As expected, the four trial *First Fixation Duration* data for Straight Jumps, Seatdrops, and Gait yielded no significant differences as both groups are likely to have similar amounts of sensorimotor experience given these tasks are more related to everyday actions. Importantly, the four trial *First Fixation Duration* group x congruency interaction in Twists supports the aforementioned suggestion because the trampolining group spent significantly greater duration on the congruent model compared the incongruent model, whereas there was no significant difference in viewing duration in the non-trampolining group when viewing the congruent and incongruent models. A possible reason for why the trampolining group spent longer viewing the congruent model when presented as a Twist is because of the extra processing time needed to evaluate, or confirm, that the observed action is a specialised Twist action that they have recently acquired over practice (Lex, Essig, Knoblauch, & Schack, 2015). Therefore, because inverting a point-light display model (incongruent model) disrupts the global form of the action leading to longer response times when tasked with identifying an observed model (Spencer, Sekuler, Bennett, Giese, & Pilz, 2016), the trampolining group most likely opted to view the congruent model because it displays the necessary task-specific orientational information related to the mechanics of performing the action (Johansson, 1975). Moreover, it has been shown that the visual-perception-action mechanism (action observation network; see Hamilton, 2013) shaped through practice results in the development of action representations and processes (Aglioti et al., 2008; Herwig et al., 2007) that are more effective and efficient leading to better scanning of congruent biological motion (Barton, Radcliffe, Cherkasova, Edelman, &

Intriligator, 2006). For example, participants that are skilled and have developed task-related representations require fewer fixations (e.g. scanning) to identify known actions than participants with less experience (Lex et al., 2015). Therefore, and although the number of fixations or neural substrate was not measured in this chapter, it is likely that the action representations (Aglioti et al., 2008; Calvo-Merino et al., 2006) developed in the trampolining group underpinned the differences in *First Fixation Location* and *Duration*, and was most likely related to neural activity located in the premotor cortex that is localised within the action observation network (Buccino et al., 2001).

Although the participants motor proficiency (it was standardised at the level of a 6 year old) was not at their chronological age (evidenced through the *MABC* data presented in *Chapter Two*), and that both groups were not different from each other, the correlation data importantly indicated that the task-specific changes in visual perception of learned actions was not related to general motor ability or autism severity. Therefore, the experience dependent effects found in the trampolining group for *First Fixation Location* and *First Fixation Duration* suggests the autistic sensorimotor system adapts based on what might be expected from typical participant motor learning studies that examined perceptual motor learning (Aglioti et al., 2008; Calvo-Merino et al., 2006). This adaptation effect is in line with the automatic imitation findings from *Chapter Three* that also indicated the perception-action system that processes lower-level biological motion into an automatic motor response (Heyes, 2011; Heyes et al., 2005) is intact in autism (Sowden et al., 2016). These adaptation effects (*Chapter Three* and *Four*) are important findings because although the sensorimotor processes underpinning learning and control are often cited as being impaired (Ament et al., 2015; Gowen & Hamilton, 2013; Haswell et al., 2009; Marko et al., 2015; Mostofsky & Ewen, 2011; Mostofsky et al., 2000) in autism, these adaptation effects indicate that sensorimotor development in autism occurred in a demographic cohort categorised as being moderate to severe. Although motor learning has been shown in high-functioning autistic adults (Foster et al., 2018; Hayes et al., 2018; Hayes et al., 2016b), the present data are some of the first to show positive adaptation in autistic adults of this severity.

Summary

The aim was to investigate whether having sensorimotor experience of trampolining would influence the perception of trampolining actions. The trampolining group and non-trampolining group were compared in their gaze behaviour on Gait and trampolining actions. There were significant differences between the groups in *First Fixation Location* and *First Fixation Duration* in Twists. The trampolining group orientated attention towards to the incongruent model but evaluated the congruent model for longer. Whereas there was no difference in how the non-trampolining group attended to or processed either model in any dependent measure. It is suggested that because Twists is the most complex and skilled movement, therefore the main differences lie within this action. Seatdrops, Straight Jumps, and Gait should be similarly familiar between the groups, and therefore no significant differences between the trampolining and non-trampolining groups would be expected. Whereas Twists is a complex and highly skilled movement in which the trampolining group only have experience of, this experience facilitates the identification of the movement through processing of the congruent model. The data presented demonstrates that perception, i.e. gaze behaviour, does change in autistic adults, as a result of sensorimotor experience of the observed action.

Chapter Five: Preferential Viewing of Autistic and Typical Kinematics

Abstract

There have been several suggestions that autistic individuals move with an atypical kinematic profile (Cook et al., 2013; Kaur et al., 2018; Torres, 2013), and that this could influence perception and gaze behaviour due to the autistic sensorimotor systems being attuned to atypical movements (de Klerk, Southgate, & Csibra, 2016; Stapel, Hunnius, Meyer, & Bekkering, 2016). Here, then, a preferential viewing study examined whether individuals with moderate to severe autism exhibited different fixation behaviour when observing a point-light display of an autistic or typical individual performing more (Straight Jumps and Gait) or less familiar (Twists and Seatdrops) actions. Overall, it was found that autistic participants did exhibit a preference to fixate on the autistic model for the familiar actions (*First Fixation Location* on first trial). Conversely, there was evidence that they preferred to fixate on the typical model for the less familiar skilled actions (*First Fixation Location* and *First Fixation Duration* across the trials, and higher *Percentage of Total Fixation Duration* on the first trial and across trials). This tendency to fixate on the typical model performing the skilled actions and the autistic model performing familiar action is consistent with the notion that experience effects preferential viewing. Specifically, because the skilled actions were still being learned (by imitating a typical coach), participants' would not have possessed the information in their sensorimotor representation to understand and predict the observed action (de Klerk et al., 2016), thus leading to preferential viewing on the typical model. Conversely, for familiar actions that existed in the autistic participant's repertoire, it is likely that the sensorimotor system was attuned to autistic kinematics.

Introduction

Most accounts of action observation suggest that motor experience is crucial for action perception (Baraglia, Copete, Nagai, & Asada, 2015; Elsner & Hommel, 2001; Prinz, 1997; Rizzolatti & Craighero, 2004; Wolpert et al., 2011; Wolpert & Flanagan, 2001). Indeed, individuals exhibit difficulty predicting actions that do not exist in their motor repertoire, although this can be overcome by forward modelling of motor behaviour, where representations of similar actions can be used to predict the visual consequences of an unknown action (de Klerk et al., 2016; Wolpert & Flanagan, 2001). Early visual experiences regulate the visuomotor system, with our own kinematics significantly impacting the perception of the kinematics of others (Cook et al., 2013; Sangrigoli et al., 2005). This is present in infancy, such that those who can crawl predict crawling more accurately than walking, whereas those who have mastered both motor skills are equally as accurate in their prediction (Stapel et al., 2016). This perception-action coupling is reflected in a strong positive correlation between one's own action ability and gaze latency (time to first fixation) when viewing other's actions (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012). This suggests that a bi-directional relationship exists between visual attention/perception and the motor system (Cannon & Woodward, 2012; Cannon et al., 2012; Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & von Hofsten, 2009; Johansson, Westling, Bäckström, & Flanagan, 2001).

Autistic individuals have difficulty generating and predicting motor tasks, in part due to an imbalance in the sensorimotor feedforward and feedback (Ronconi, Gori, Ruffino, Molteni, & Facoetti, 2013; Takarae et al., 2004a; Takarae et al., 2007). This can result in greater sensorimotor delays and impaired sensorimotor integration, which adversely affects the development of the motor system (e.g., internal action models) and thereby social and communicative behaviours. Autism severity is related to greater reactivity to environmental motion (Freitag et al., 2007; Gepner & Mestre, 2002; Mostofsky et al., 2006) and a motor ability that is significantly different to the typical population (Fournier et al., 2010). Accordingly, the kinematic profile of an individual with autism is different to that of a typical individual. This is important because as well as social functioning requiring effective coordination of language with non-verbal behaviours such as posture, limb and facial gestures, and eye contact, it is crucial to be able to interpret and respond appropriately to the actions of others (Hannant et al., 2016b).

If sensorimotor connections are bidirectional, sensory representations propagate to the motor representation and vice versa (Heyes, 2001, 2010, 2011). Therefore, learning can occur through self-observation, and autistic individuals may develop different representations to typical individuals due to motor differences (Cook et al., 2013; Edey, Yon, Cook, Dumontheil, & Press, 2017). Autistic kinematics differ from typical kinematics in that autistic individuals have a longer preparation phase before motor execution, with difficulties specifying muscular force (from known motor problems, see Gowen & Hamilton, 2013) which is compensated for with variability in the initial phase of motor execution (Glazebrook et al., 2006). Therefore, typical kinematics would have a faster preparation than autistic, and there would be a smoother limb deceleration during the online control phase of the movement (Glazebrook et al., 2006). It then follows that their visual system would be attuned to autistic rather than typical kinematics (Cook et al., 2013; Heyes, 2011; Sangrigoli et al., 2005). That is, autistic individuals should have representations that are specific to autistic kinematics, and a sensorimotor system that is attuned to these atypical kinematics (Cook, 2016; Cook & Bird, 2012; Cook et al., 2013; Cook et al., 2014a). This leads on to the research question, *do individuals with moderate to severe autism exhibit preferential attention to autistic compared to typical kinematics.*

Study 1: Preferential Viewing Protocol

Method

Participants

The original sample of 30 participants was comprised of six females, with an age range of 20-55 years (*M* = 34.00, *SD* = 13.15), and 24 males with an age range of 21-52 years (*M* = 31.38, *SD* = 9.65). Problems encountered in this study with the attention span of the participant, and/or behavioural problems (such as turning equipment off, leaving during collection, or not looking at the screen) meant four individual's data were removed as their data was poor quality. This left a total of 26 participants, with an average of 147 hours of trampolining experience (see Table 21 for individuals' hours of experience), of which there five females, with an age range of 20-55 years (*M* = 36.20, *SD* = 13.41), and 21 males with an age range of 21-52 years (*M* = 30.67, *SD* = 9.36). This was an opportunity sample, using individuals from the drill centre (Birkenhead Trampolining Centre) in the AutismAbility project. Participants had normal or corrected-to-normal vision and were screened via their person-centred plans for the following exclusion criteria: dyspraxia, dyslexia, epilepsy, and other neurological or psychiatric conditions, sample characteristics are presented in Table 22.

Participants were approached by the researcher, their support worker, or the group lead to establish their willingness to participate. The researchers were clear that the personal interests of the participants were of the utmost importance, with all invited participants allowed as much time as necessary to make a decision regarding their involvement in the study. Where possible, consent was obtained from the participants, however, in certain cases it was necessary to refer to the Mental Capacity Act (2005) to establish a participant's capacity to make a decision. This process was facilitated by one-to-one support workers, group leads, and activity leaders. Once the capacity to consent to participate was established, all necessary measures were completed for each participant before starting the protocol. The experiment received clearance from the Liverpool John Moores University ethics committee.

Table 21. *Number of hours of experience trampolining retrospectively calculated for each participant.*

Participant	**Experience (hours)**
1	198
2	121
3	196
4	146
5	170
6	144
7	147
8	146
9	180
10	147
11	138
12	200
13	107
14	136
15	147
16	35
17	135
18	144
19	143
20	94
21	148
22	70
23	158
24	208
25	209
26	161

Table 22. *Participant Demographics.*

		Mean (*SD*)
n		26
	Gender	5 females
VIQ		33 (20)
	Age Equivalent	4 years 4 months
SRS	*t*-score	78 (7)
	AWR	73 (15)
	COG	76 (14)
	COM	75 (10)
	MOT	67 (14)
	RRB	77 (13)
	SCI	78 (7)
SP	Seeking	44 (10)
	Avoiding	54 (11)
	Sensitivity	49 (9)
	Registration	51 (12)
	Auditory	24 (4)
	Visual	16 (4)
	Touch	26 (4)
	Movement	19 (5)
	Body Position	13 (5)
	Oral	19 (8)
	Conduct	21 (5)
	Social Emotional	41 (8)
	Attentional	30 (7)
MABC	Total Test	6 (5)
	Manual Dexterity	9 (7)
	Aiming & Catching	7 (5)
	Balance	3 (3)

VIQ – Verbal IQ, measured by the Peabody Picture Vocabulary Test (fourth edition)

SRS – Social Responsiveness Scale (second edition)

SP – Sensory Profile (second edition)

MABC – Movement Assessment Battery for Children (second edition).

Stimuli

The stimuli used for this study is the same as outlined in *Chapter Four*, including point-light displays of three trampolining actions (Twists, Seatdrops, and Straight Jumps) and Gait. The actions were demonstrated by an autistic and typical model, which were upright and synchronised on the computer screen (see Figure 16).

Figure 16. Point-light displays used for Preferential Viewing Protocol, autistic model (left) and typical model (right).

Procedure

The procedure used for this study is the same as outlined in *Chapter Four*, participants also did not know what they would watching for this study, they did not know what the actions would be or that the models would be different. Participants understanding of the models was tested post-test, of the participants who could answer (n = 12), they were asked two questions:

what did you watch? and can you do that? Participants all answered that they could perform the movements, with answers like ‘trampolining like me’, six participants stated that they were two different people (this was further examined in a more inclusive protocol in the Recognition Study). Using a preferential viewing protocol, point-light displays of an autistic and a typical individual were displayed. Eye movement behaviour was recorded while participants watched the point-light displays.

Data Analysis

Data was analysed for the first trial that included a fixation on the point-light display, as well as the average over the four trials. *First Fixation Location* (binary for first trial or percentage for four trials), *First Fixation Duration*, and *Percentage of Total Fixation Duration* were determined using tobii studio and then used to quantify preferential attention. This involved 2 models (autistic or typical) that were observed performing the four actions (Twists, Seatdrops, Straight Jumps, Gait). Based on familiarity, these actions were classified as either familiar (Straight Jumps; Gait) or skilled (Twists; Seatdrops) and were analysed separately. Data validity (gaze sample percentage) range from 14-99 (M = 63.50).

First Fixation Location was determined using *time to first fixation*. The side of the screen (autistic or typical model) with the lowest time to first fixation was determined as the location that the participant first fixated on. For example, if a participant took 786 milliseconds to fixate on the autistic model, and 1856 milliseconds to fixate on the typical model, it follows that the participant fixated on the autistic model first. This was expressed as binary data for the first trial that the participant fixated on (i.e., 0 = autistic; 1 = typical). *First Fixation Location* data for the first trial was submitted to a Chi Square test of independence, which is suitable for binary data that is not normally distributed.

First Fixation Duration was defined as the duration of the first fixation made on the areas of interest. *Percentage of Total Fixation Duration* was calculated by dividing the total fixation duration for each side of the screen by the sum of the total fixation duration on both the autistic and typical sides. Intra-participant mean data was calculated from the four trials in each combination of model and action. *Percentage of First Fixation Location, First Fixation Duration,* and *Percentage of Total Fixation Duration* for each action were submitted to separate 2 Model (autistic; typical) x 2 Action (familiar = Straight Jumps; Gait: skilled = Twists; Seatdrops) ANOVAs. Alpha was set at $p < 0.05$, and partial eta-squared (η_p^2) expressed the size of the effect. Significant interactions effects were decomposed using the multiple *t*-tests for which Type I error was control (Alpha was set to $p < 0.01$).

Results

First Fixation Location

First Trial Data.

Frequency data for observed and expected values for actions and model for the first trial are presented in Table 23. In Straight Jumps, there was a significant difference between the expected and observed values (χ^2 (1) = 5.26, $p < 0.05$). There were no significant deviations from the expected values in Twists (χ^2 (1) = 2.33, $p > 0.05$), Seatdrops (χ^2 (1) = 0.17, $p > 0.05$), or Gait (χ^2 (1) = 1.00, $p > 0.05$). The data shows that in Straight Jumps, participants attended to the autistic model first.

Four Trial Data.

The *First Fixation Location* data as a function of model and action are illustrated in Figure 17. ANOVA on these data revealed a significant main effect of model in the skilled actions (F (1, 12) = 11.43, $p < 0.005$, $\eta p^2 = 0.49$). Participants exhibited a higher *Percentage of First Fixation Location* on the typical than autistic models. There was no main effect of action, (F (1, 12) = 0.72, $p > 0.05$, $\eta p^2 = 0.06$), or interaction between model and action (F (1, 12) = 0.33, $p > 0.05$, $\eta p^2 = 0.03$) for the skilled actions. There were no significant main or interaction effects for the familiar actions [model, F (1, 14) = 2.39, $p > 0.05$, $\eta p^2 = 0.15$; action, F (1, 14) = 0.44, $p > 0.05$, $\eta p^2 = 0.04$; interaction, F (1, 14) = 0.16, $p > 0.05$, $\eta p^2 = 0.01$].

Table 23. *Frequencies of observed and expected values on the two models (autistic and typical) for First Fixation Location for the skilled and familiar actions.*

		Autistic	Typical	Expected	Residual	Significance
Skilled	**Twists**	14	7	10.5	-3.5	0.13
	Seatdrops	13	11	12.0	-1.0	0.68
Familiar	**Straight Jumps**	17	6	11.5	-5.5	0.02 *
	Gait	15	10	12.5	-2.5	0.32

$p < 0.05$*

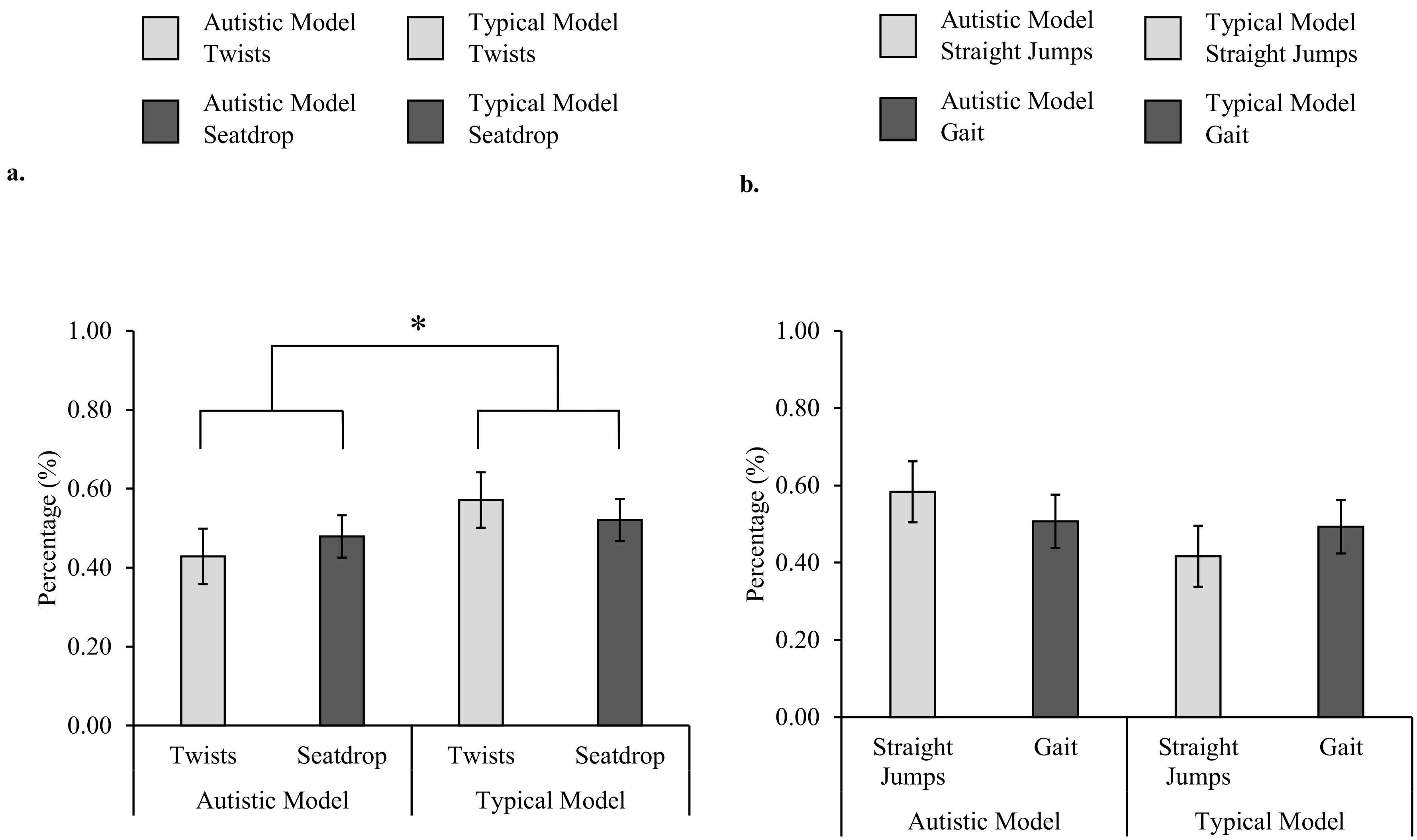

Figure 17. Percentage of First Fixation Locations on the autistic and typical models across the trials for the skilled actions (a) Twists represented by the light grey bars and Seatdrops by the dark grey bars, and the familiar actions (b) Straight Jumps represented by the light grey bars and Gait by the dark grey bars, with standard error of the mean (error bars).

First Fixation Duration

First Trial Data.

The *First Fixation Duration* data for the first trial is illustrated in Figure 18. For the skilled actions, ANOVAs revealed no significant main or interaction effects [model, F (1, 9) = 0.27, $p > 0.05$, $\eta p^2 = 0.03$; action, F (1, 9) = 1.95, $p > 0.05$, $\eta p^2 = 0.18$; interaction, F (1, 9) = 1.90, $p > 0.05$, $\eta p^2 = 0.18$]. There were also no differences for the familiar actions [model, F (1, 12) = 0.02, $p > 0.05$, $\eta p^2 = 0.01$; action, F (1, 12) = 1.04, $p > 0.05$, $\eta p^2 = 0.08$; interaction, F (1, 12) = 0.84, $p > 0.05$, $\eta p^2 = 0.07$]. As displayed in Figure 18, the duration of the first fixation was similar across all the viewed stimuli.

Four Trial Data.

The *First Fixation Duration* data averaged across trials is illustrated in Figure 19. For skilled actions, there were no significant main or interaction effects [model, F (1, 13) = 2.12, $p > 0.05$, $\eta p^2 = 0.14$; action, F (1, 13) = 0.07, $p > 0.05$, $\eta p^2 = 0.01$; interaction, F (1, 13) = 0.19, $p > 0.05$, $\eta p^2 = 0.01$]. However, for familiar actions, ANOVA revealed a significant main effect of model (F (1, 15) = 4.87, $p < 0.05$, $\eta p^2 = 0.25$). *First Fixation Duration* on the autistic model was significantly longer than on the typical model (see Figure 19b). There was no main effect of action (F (1, 15) = 0.11, $p > 0.05$, $\eta p^2 = 0.01$) or interaction between action and model (F (1, 15) = 0.84, $p > 0.05$, $\eta p^2 = 0.05$).

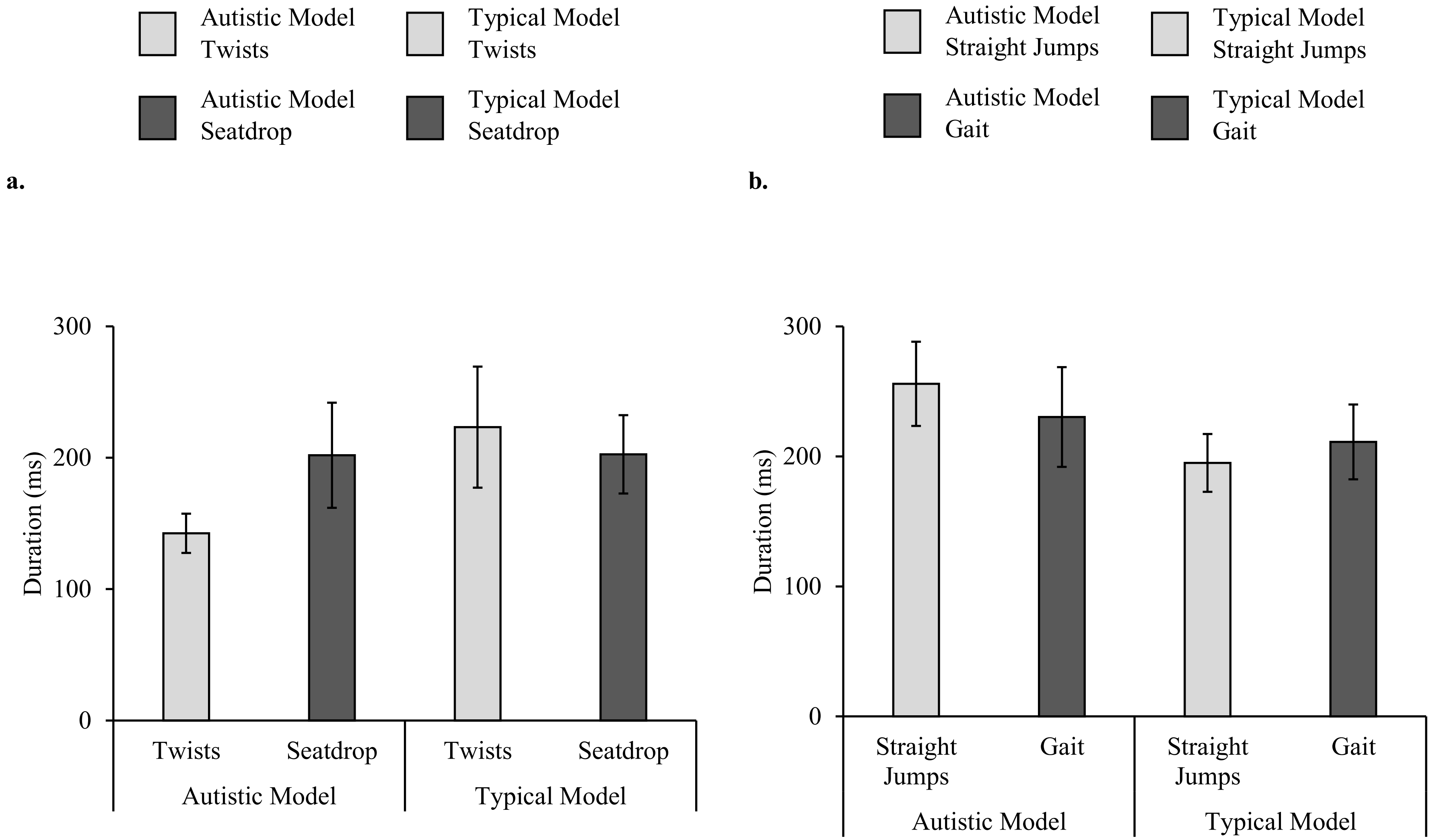

Figure 18. First Fixation Duration for the first trial data on the autistic and typical models for the skilled actions (a) Twists represented by the light grey bars and Seatdrops by the dark grey bars, and the familiar actions (b) Straight Jumps represented by the light grey bars and Gait by the dark grey bars, with standard error of the mean (error bars).

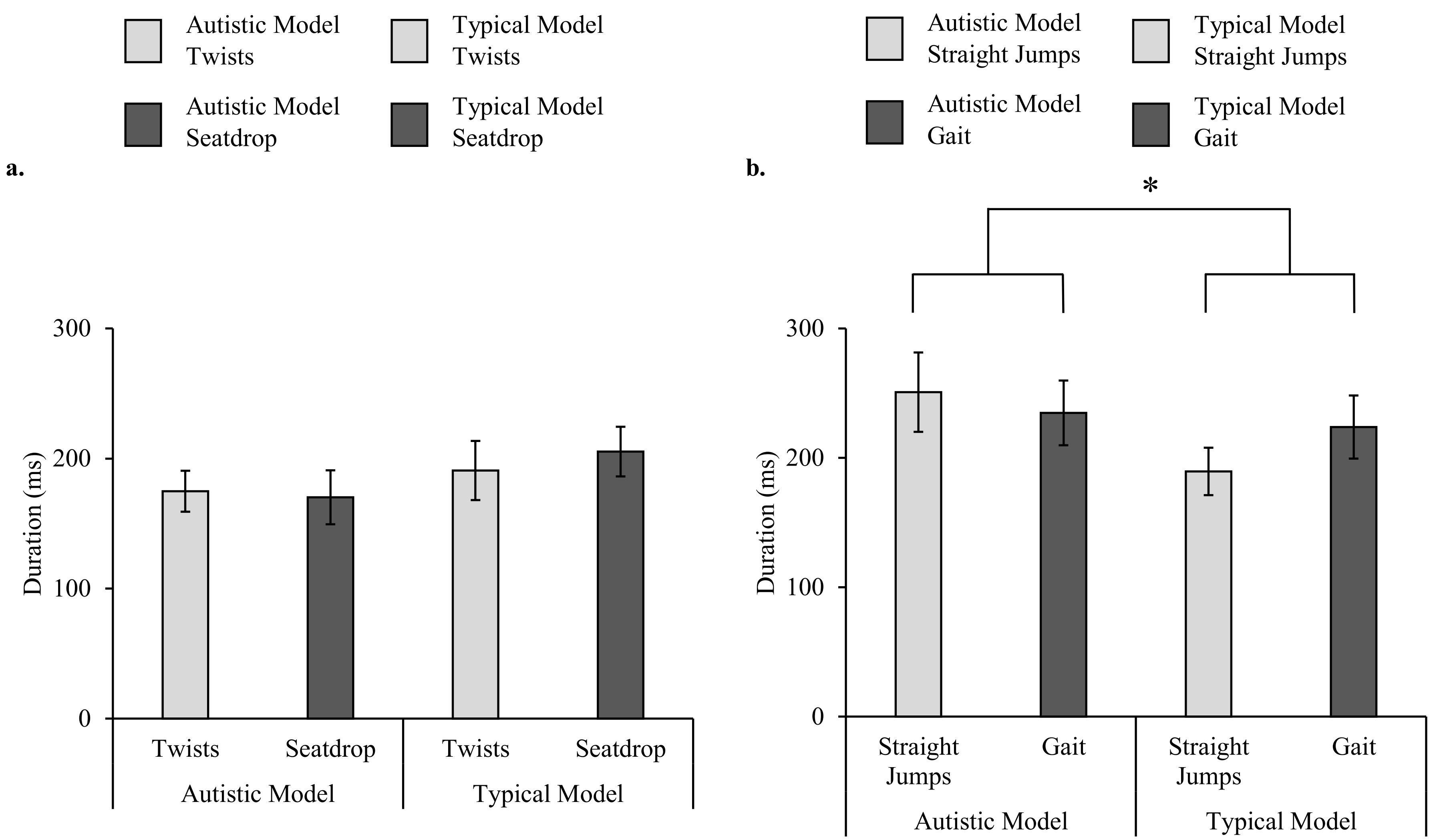

Figure 19. First Fixation Duration across the trials on the autistic and typical models for the skilled actions (a) Twists represented by the light grey bars and Seatdrops by the dark grey bars, and the familiar actions (b) Straight Jumps represented by the light grey bars and Gait by the dark grey bars, with standard error of the mean (error bars).

Percentage of Total Fixation Duration

First Trial Data.

The *Percentage of Total Fixation Duration* data for the first trial is illustrated in Figure 20. ANOVA revealed a significant main effect of model for the skilled actions (F (1, 9) = 10.86, $p < 0.01$, $\eta p^2 = 0.55$). Participants exhibited a higher *Percentage of Total Fixation Duration* on the typical than autistic model (see Figure 20a). There was no main effect of action (F (1, 9) = 0.48, $p > 0.05$, $\eta p^2 = 0.05$) or interaction between action and model (F (1, 9) = 0.20, $p > 0.05$, $\eta p^2 = 0.02$). For the familiar actions, there was no significant main or interaction effects [model, F (1, 12) = 2.03, $p > 0.05$, $\eta p^2 = 0.14$; action, F (1, 12) = 1.18, $p > 0.05$, $\eta p^2 = 0.09$; interaction, F (1, 12) = 0.83, $p > 0.05$, $\eta p^2 = 0.07$]. As displayed in Figure 20a and 20b, participants had a higher *Percentage of Total Fixation Duration* on the typical model in the skilled actions.

Four Trial Data.

The *Percentage of Total Fixation Duration* data across the trials is illustrated in Figure 21. ANOVA revealed a significant main effect of model for the skilled actions (F (1, 13) = 6.76, $p < 0.05$, $\eta p^2 = 0.34$). Participants exhibited a higher *Percentage of Total Fixation Duration* on the typical than autistic model (see Figure 21a). There was no main effect of action (F (1, 13) = 0.93, $p > 0.05$, $\eta p^2 = 0.07$) or interaction between action and model (F (1, 13) = 0.14, $p > 0.05$, $\eta p^2 = 0.01$). There was no significant main or interaction effects for the familiar actions [model, F (1, 13) = 0.57, $p > 0.05$, $\eta p^2 = 0.04$; action, F (1, 13) = 0.56, $p > 0.05$, $\eta p^2 = 0.04$; interaction, F (1, 13) = 0.04, $p > 0.05$, $\eta p^2 = 0.01$]. As displayed in Figure 21a and 21b, participants had a higher *Percentage of Total Fixation Duration* on the typical than autistic model when viewing the skilled actions.

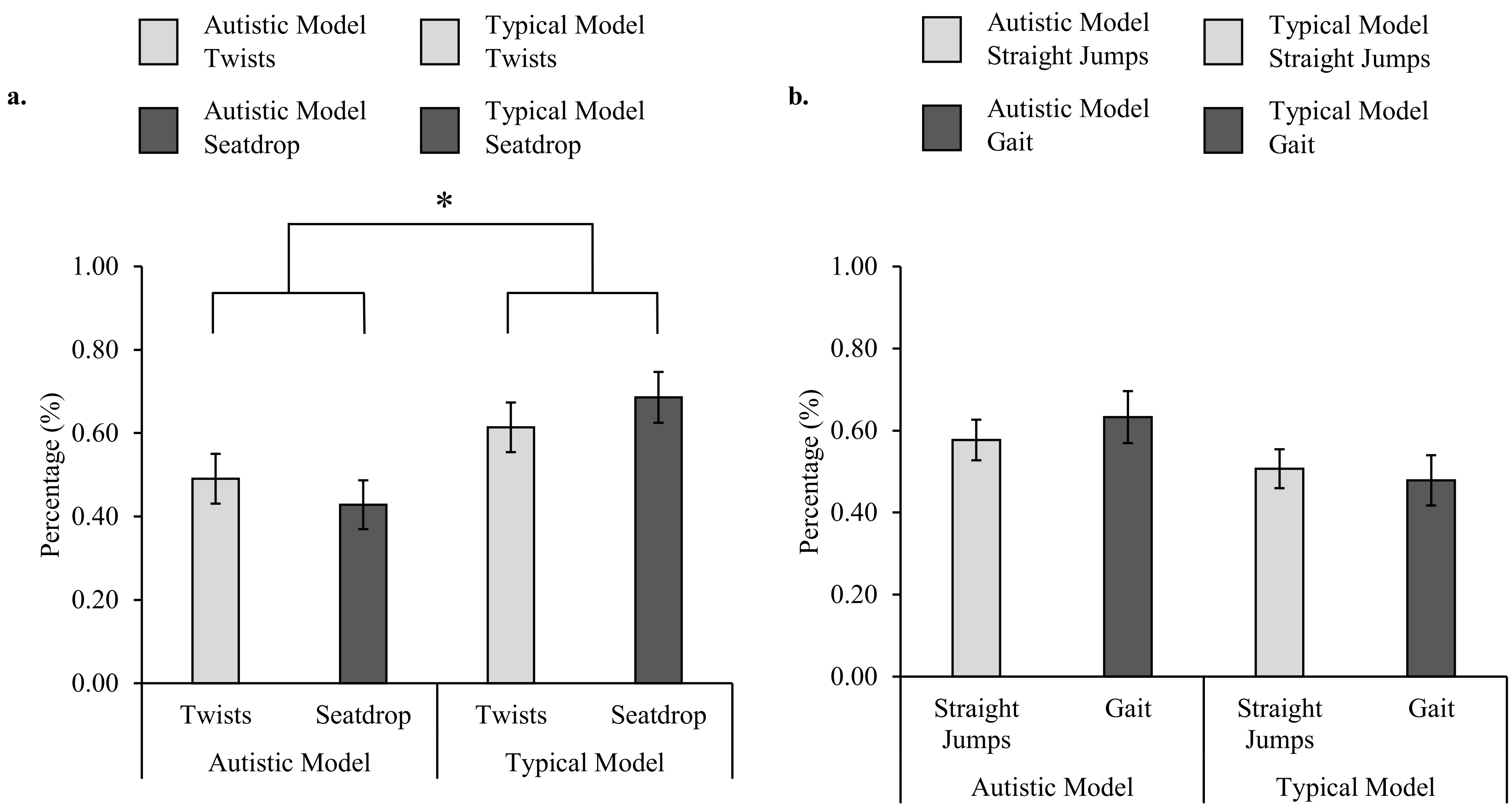

Figure 20. Percentage of Total Fixation Duration on the autistic and typical models for the first trial data for the skilled actions (a) Twists represented by the light grey bars and Seatdrops by the dark grey bars, and the familiar actions (b) Straight Jumps represented by the light grey bars and Gait by the dark grey bars, with standard error of the mean (error bars).

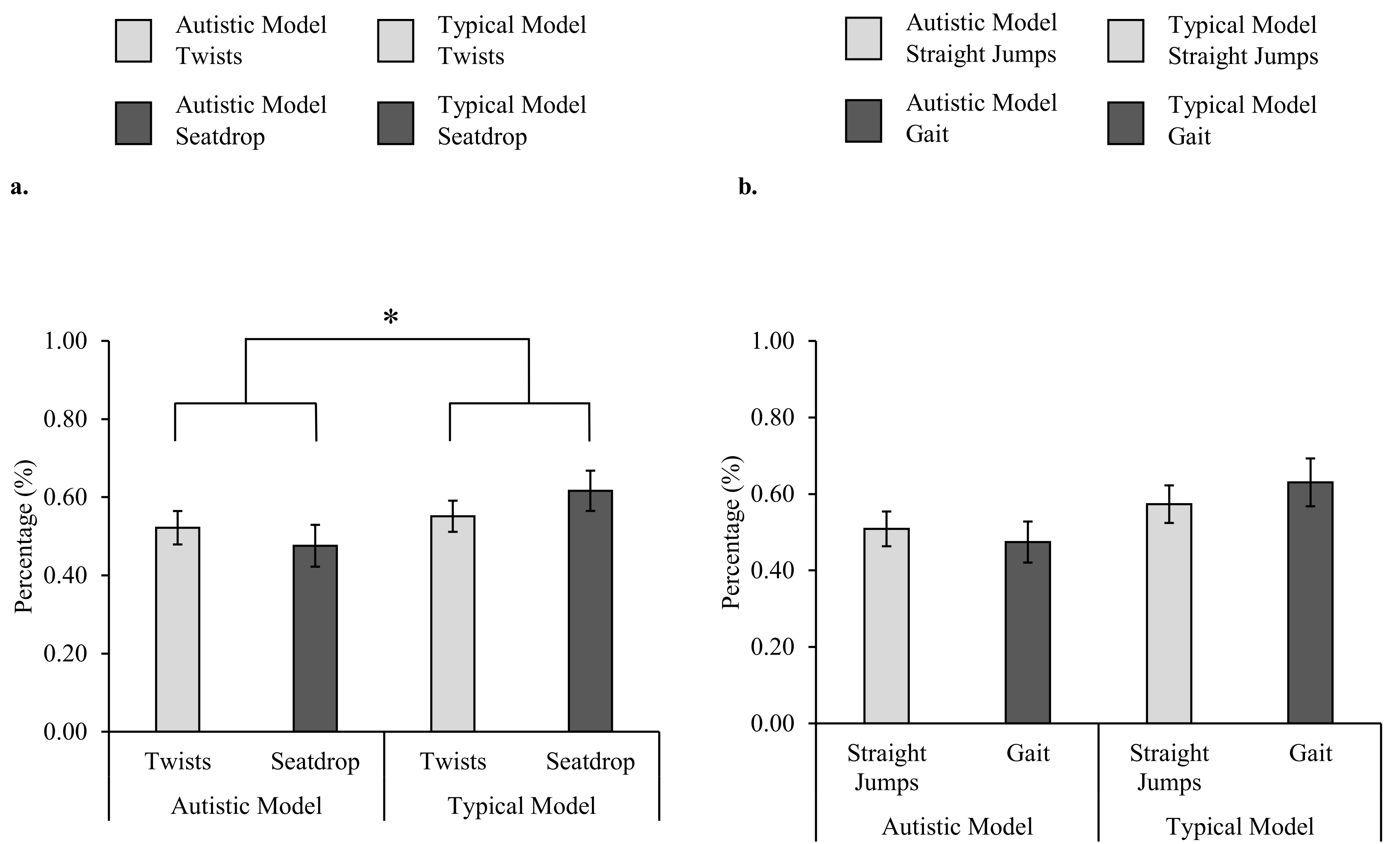

Figure 21. Percentage of Total Fixation Duration on the autistic and typical models across the trials for the skilled actions (a) Twists represented by the light grey bars and Seatdrops by the dark grey bars, and the familiar actions (b) Straight Jumps represented by the light grey bars and Gait by the dark grey bars, with standard error of the mean (error bars).

Study 2: Recognition Task

Method

Participants

There were 34 participants, comprised of 16 females, with an age range of 20-60 years (*M* = 27.50, *SD* = 13.01), and 18 males with an age range of 21-57 years (*M* = 30.06, *SD* = 11.54). These were allocated to two groups according to their diagnosis, a typical group (n = 20), with an age range of 20-57 years (*M* = 25.45, *SD* = 10.70), consisting of 14 females, with an age range of 20-55 years (*M* = 24.07, *SD* = 9.10), and 6 males with an age range of 21-57 years (*M* = 28.67, *SD* = 14.21). The autistic group (n = 8), who all completed the preferential viewing study, had an age range of 24-59 years (*M* = 37.88, *SD* = 12.77), and consisted of 2 females, with an age range of 43-59 years (*M* = 51.00, *SD* = 11.31), and 6 males with an age range of 24-52 years (*M* = 33.50, *SD* = 10.54). This was an opportunity sample, using individuals in two different sites, the drill centre (trampolining centre) in the AutismAbility project (for the autistic group), and students from around the university campus. Participants had normal or corrected-to-normal vision and were screened via their person-centred plans for the following exclusion criteria: dyspraxia, dyslexia, epilepsy, and other neurological or psychiatric conditions, sample characteristics are presented in Table 24.

Participants were approached by the researcher, their support worker, or the group lead to establish their willingness to participate. The researchers were clear that the personal interests of the participants were of the utmost importance, with all invited participants allowed as much time as necessary to make a decision regarding their involvement in the study. Where possible, consent was obtained from the participants, however, in certain cases it was necessary to refer to the Mental Capacity Act (2005) to establish a participant's capacity to make a decision. This process was facilitated by one-to-one support workers, group leads, and activity leaders. Once the capacity to consent to participate was established, all necessary measures were completed for each participant before starting the protocol. The experiment received clearance from the Liverpool John Moores University ethics committee.

Stimuli

Participants viewed the same point-light displays as in Study 1: Preferential Viewing Protocol, except only a single model was on the screen at any one time. The two models were the same as in the preferential viewing protocol, the autistic and the typical model. They displayed Twists, Seatdrops, Straight Jumps, and Gait.

Design

The independent variables were model (autistic_m, typical_m), and group (autistic_g, typical_g). The dependent variable was the number of correct answers given.

Table 24. *Participant Demographics.*

		Mean (*SD*)
n		8
	Gender	2 females
VIQ		51 (20)
	Age Equivalent	6 years 4 months
SRS	*t*-score	69 (10)
	AWR	67 (14)
	COG	70 (8)
	COM	67 (11)
	MOT	62 (10)
	RRB	71 (10)
	SCI	68 (10)
SP	Seeking	37 (12)
	Avoiding	46 (9)
	Sensitivity	39 (8)
	Registration	44 (10)
	Auditory	20 (5)
	Visual	12 (2)
	Touch	22 (6)
	Movement	16 (6)
	Body Position	11 (3)
	Oral	16 (8)
	Conduct	18 (4)
	Social Emotional	35 (6)
	Attentional	24 (6)
MABC	Total Test	5 (5)
	Manual Dexterity	7 (7)
	Aiming & Catching	7 (6)
	Balance	3 (3)

VIQ – Verbal IQ, measured by the Peabody Picture Vocabulary Test (fourth edition)

SRS – Social Responsiveness Scale (second edition)

SP – Sensory Profile (second edition)

MABC – Movement Assessment Battery for Children (second edition).

Procedure

The researcher sat at a right angle to the participant in front of a laptop that controlled the experiment. Participants sat in front of a 20-inch LCD screen (resolution 1600 x 900, refresh rate 75Hz), at a viewing distance of 45-100cm, which was the external screen the eye-tracker was mounted on. The instruction participants were given was to watch the two videos, and then told they will be asked at the end of the two whether they were the same or different.

Two point-light displays were shown one after the other, each for a duration of 8 seconds. A typical trial started with a two-second blank screen, then the first point-light display, another two-second blank screen, then the second point-light display. This was followed by a screen with the text "Same or Different" (see Eaves, Behmer, and Vogt (2016)). Participants who were minimally verbal were given a sheet with words same and different and were asked to point to their answer. If the participant used PECS (Picture Exchange Communication System) and had appropriate same or different pictures, they could give those to the researcher as their answers. Verbal participants could either point or verbalise their answer. Participants were not given any feedback on their answers during the task or afterwards, so that if participants did not get many answers correct, they were not discouraged by this.

Participants completed a total of 12 trials. These comprised the two models (autistic or typical) shown in two trial types (same or different). For example, the autistic model was seen preceding a different typical model and typical model preceding autistic model (different trial), or the same autistic model (same trial). The order of the trial type (same or different) and action was pseudo-randomised. The total experiment time was approximately 5 minutes.

Data Analysis

To examine if the autistic participants could identify a point-light display at the same level as the typical participants, the number of correct answers (correctly identifying the model as being the same or different) were submitted to independent-samples *t*-tests.

Results

The mean number of correct answers for both the autistic and typical group scores can be found in Table 25. An independent samples *t*-test indicated that there were no significant differences in the scores between the autistic and control groups, $t\ (26) = -1.98$, $p > 0.05$. A subsidiary analysis with the trial types separated, indicated no significant difference between the groups for the different trials, $t\ (26) = -1.50$, $p > 0.05$, or for the same trials, $t\ (26) = -1.28$, $p > 0.05$. A one-sample *t*-test was used to confirm that the scores for the total test were significantly different to 50% chance (i.e. guessing could result in a score of 6 out of 12 given the 2 possible answers). The *t*-test revealed that the total test score was significantly greater than a score of 6, $t\ (27) = 9.68$, $p < 0.00001$, which means that participants performed better than chance.

Table 25. *Means and standard deviations for the number of correct answers for the autistic and typical groups.*

	Autistic Group	Typical Group
Same trials	5.75	6.55
(/ 8)	(1.98)	(1.28)
Different trials	2.50	3.10
(/ 4)	(.93)	(.97)
Total	8.25	9.65
(/ 12)	(1.67)	(1.69)

Discussion

In the present chapter, the first study examined whether individuals with moderate to severe autism preferentially attended to a point-light display of an autistic individual or a typical individual. The preferential viewing protocol displayed two different point-light displays (autistic kinematics and typical kinematics) performing the same action in synchrony, presented side-by-side on a split-screen monitor. Gaze behaviour was quantified using *First Fixation Location*, *First Fixation Duration*, and *Percentage of Total Fixation Duration*. The *First Fixation Location* data indicated that the autistic participants orientate towards the autistic model performing Straight Jumps (i.e., familiar action) in their first fixation on the first trial. However, the *First Fixation Duration* was similar across all the viewed stimuli, and participants then spent a higher *Percentage of Total Fixation Duration* during the first trial on the typical model in the skilled actions. When averaged across the four trials, there was shift in behaviour such that participants exhibited a higher *Percentage of First Fixation Location* on the typical model compared to the autistic model in the skilled actions. The duration of the first fixation across the four trials was similar for the skilled actions across the autistic and typical models. However, when viewing the familiar actions, *First Fixation Duration* across the four trials was longer on the autistic model (251 ms) compared with the typical model (190 ms). For the *Percentage of Total Fixation Duration*, participants spent longer fixating on the typical model compared with the autistic model when viewing skilled actions.

In the second study, where the models were compared in the Recognition Task, it was found that autistic participants were equally as capable as typical control participants at discerning a model showing autistic or typical kinematics. Out of a total score of 12 correct answers, autistic participants achieved 8.25 correct answers compared to 9.65 correct answers for the typical participants. This is important because it indicates that the findings from the preferential viewing study were not simply a consequence of difficulties experienced by autistic participants in recognising the different point-light displays. Autistic participants clearly knew when they were observing two different models, which may have been based on a greater reliance local features to classify the stimuli (Cook et al., 2014a; Pierno, Mari, Lusher, & Castiello, 2008). It is reasonable, therefore, to assume that the fixation data reflects the autistic participants preferred gaze orientation when viewing an autistic vs. typical model performing either familiar or skilled actions.

Autistic participants who completed the preferential viewing protocol had more experience in the familiar actions (Straight Jumps and Gait) and should thus has stronger sensorimotor representations. The skilled actions (Twists and Seatdrops) are taught movements with specific criteria to meet the BAGA award, for example, placement of the arms and pointing of the toes. Therefore, the sensorimotor representations of these movements were likely still being developed, in part been based on observing kinematics from the typical coach.

The fixation duration data are consistent with these experience dependent differences. That is, *First Fixation Duration* (averaged across trials) and *Percentage of Total Fixation Duration* (first trial and averaged across) were longer on the typical model in the less familiar skilled actions. Conversely, autistic participants exhibited a preference to fixate longer on the autistic model for the more familiar actions. In this latter situation, it can be expected that the kinematics of the autistic model would resonate with the autistic participants motor system (Cook et al., 2013; Heyes, 2011; Sangrigoli et al., 2005), thus leading to better action prediction of the movement by extrapolating the action goal (Pomiechowska & Csibra, 2017) and preferred fixation.

The *First Fixation Location* data were somewhat more mixed but can still be interpreted in line with the experience dependent effect. For example, participants exhibited a preference to orient their first fixation to the autistic model performing Straight Jumps on the very first trial. However, when averaged over the four trials, it was apparent that participants showed a preference to orient their first fixation on the typical model compared to the autistic model in the skilled actions. The suggestion is that having shown a mild preference to initially fixate on the autistic model, participants were subsequently initially attracted to the novel typical model performing less familiar skilled actions, which were fixated on for longer in order to permit evaluation of the observed kinematics. The influence of the nature of the observed kinematics on perception has also been shown in typical participants, who exhibited better prediction of their own kinematics compared to those of a different typical individual (Sebanz, Knoblich, & Prinz, 2003; Wilson & Knoblich, 2005). Similarly, de Klerk et al. (2016) and Stapel et al. (2016) found the infants who had no motor experience of a movement, but had visual experience, fixated longer on the model which best fitted their visual representation of the movement being shown. This leads to the conclusion that prediction and understanding of observed action is better when there is greater correspondence between the observed and one's own action kinematics. This experience would be two-fold for the trampolining group, as they have sensorimotor experience of the trampolining movements and also the autistic kinematics over the typical kinematics. Through experience, direct visual tuning from self-observation and motor contributions to perception, is thought to tune perceptual models of actions according to our own kinematics and movements (Edey et al., 2017). Which is consistent with the notion that the sensory representation of the action propagates to the motor representation of the action (Heyes, 2001, 2010, 2011), thereby creating a sensorimotor representation that is attuned to one's own kinematics. Due to the motor difficulties in autism at a gross and fine level (Gowen & Hamilton, 2013; Gowen & Poliakoff, 2012), autistic individuals may develop different representations to typical individuals, with representations attuned to motor differences that do not accord with typical kinematics (Cook et al., 2013; Sangrigoli et al., 2005). In the case of the skilled actions observed in the current study, which were still being learned by imitating a typical coach, and therefore the information needed to understand and predict could not be derived entirely from one's own sensorimotor representation (de Klerk et al., 2016). Therefore, it followed that these actions attracted participants attention when displayed by the typical model.

It is also relevant to comment that although autistic participants in this study had several years of sensorimotor experience of the skilled actions, they would have had more visual experience of the coach performing the action than they would have motor experience. Indeed, although they had accrued an average of 147 hours of trampolining experience, this would have involved more than practicing only the four trampolining actions investigated here. It would therefore be expected that for the specialised, skilled actions of Twists and Seatdrops, there would have been more visual experience from watching the typical coach than motor experience of actually performing the movements. Less or no dominance of visual experience should have been present in the familiar actions of Straight Jumps and Gait, which participants had physically performed on many more occasions. For the first fixation on the first trial, this was the case, as the visual experience of the typical coach was not dominant over the motor experience of performing Straight Jumps and Gait, as attention was drawn to the autistic model, whereas in the averaged four trial data in the skilled actions, attention was drawn to the typical model.

In previous studies (Deschrijver et al., 2017a; Oberman et al., 2005; Théoret et al., 2005), it has been common to use a typical model when investigating action observation in autistic individuals. This had led to the mistaken conclusion that the action observation system is broken in autism, with a lack of mu rhythm suppression leading to the suggestion that the action observation system is not activating in the same way as it does with typical individuals. However, mu rhythm suppression occurs in typical participants observing typical models, for which their sensorimotor system is attuned. This is not the case when autistic individuals observe typical models. Also, autistic individuals are also thought to rely more on self-generated actions (Haswell et al., 2009), and have an action observation system that is more reliant on proprioceptive feedback than is the case in typical individuals. The implication is that whether studying action observation or preferential viewing, it is important to consider the nature of the model presented to autistic participants and whether it depicts kinematics that are attuned to the autistic sensorimotor system.

The studies in this chapter have some potential limitations. In the preferential viewing study (Study 1), it may have been informative to include a control group of typical participants in order to determine if their preferential attention differed from that of the autistic group. For example, it may have been the case that typical participants initially viewed the typical model but then spent proportionately longer viewing the autistic model because it displayed atypical kinematics. Or, they may have shown the same preferential viewing strategy as the autistic participants. Either way, the inclusion of a typical group would have provided a useful baseline against which to compare the autistic group. Similarly, it could have been interesting to include a group of low to mild severity autistic participants to determine if autism severity influenced preferential viewing. Finally, had it been possible to collect motion capture data with a moderate or severely autistic adult, it would have been interesting to examine whether the severity of the autistic model influenced preferential viewing. For example, it may have been that participants with moderate to severe autism are more likely to resonate with a model displaying similar kinematics (i.e. greater motor disturbance, see Travers, Powell, Klinger, and Klinger, 2013), and thus exhibit different gaze behaviour or an affinity to the more severe model over the model with mild autism. In terms of Study 2, a more detailed understanding of the perceptual ability of the participants could have been gained by including more models (autistic and typical) performing the skilled and familiar actions. This would have helped rule out any possibility that a particular feature of the observed kinematics (e.g., difference in magnitude of arm movement) was used to make the perceptual judgment and that participants were actually discriminating based on a generic autistic vs typical movement kinematics. The inclusion of more models would also have enabled more trials to be included although care would have to been taken not to exceed the attention span of the moderate to severe autistic participants.

Summary

To conclude, the primary aim of this chapter was to investigate if individuals with moderate to severe autism exhibit preferential attention (i.e., location and duration) to autistic kinematics. To this end, autistic participants observed familiar actions (Straight Jumps and Gait) and skilled actions (Twists and Seatdrops) performed by an autistic or typical model. Overall, it was found that autistic participants did exhibit a preference to fixate on the autistic model for more familiar actions. Conversely, there was evidence that they preferred to fixate on the typical model for the less familiar skilled actions. This difference in preferential viewing is discussed with reference to sensorimotor experience of the observed stimuli. The findings presented in *Chapter Five* are consistent with the suggestion that the sensorimotor system in autistic individuals is attuned to autistic kinematics.

Chapter Six: Is There Experience Dependent Pursuit in Autistic Adults?

Abstract

Experience of an action and the associated motor representation provides information for prediction of observed movements, which allows for more accurate and efficient anticipation and predictive eye movements (Badler & Heinen, 2006; Elsner et al., 2013; Gray, 2002). The current study examined eye movements as participants with and without trampolining experience viewed point-light displays of an autistic model performing trampolining actions. This follows on from *Chapter Four,* in which the effect of experience on preferential viewing was examined. Only the trampolining group has sensorimotor experience of the movements and thus could be expected to exhibit different eye movements compared to the non-trampolining group. Participants were asked to follow a point-light display on screen performing Straight Jumps and Seatdrops. There were no significant differences between the trampolining and non-trampolining groups found in the total duration, average duration, or count of eye movements. This means the participants performed similarly, independent of experience, and tracked the point-light displays with a similar number and duration of eye movements. The implication is that the task-specific representations developed by the trampolining group through practice did not facilitate pursuit. Accordingly, a deficit in overt gaze orientation an associated visual processing is unlikely to account for findings in *Chapters Four* and *Five* where there was a difference in preferential viewing related to the first fixation.

Introduction

When interacting within our surrounds, we are commonly faced with objects that move relative to the retina, either because of self (i.e., head) and/or object motion. To avoid/minimize constant movement of an object of interest across the retina, and thus blurred vision, the normal response is to move the eyes. However, when attempting to maintain a moving object of interest on the high acuity region of the retina (i.e., fovea) using smooth pursuit, it is insufficient to rely upon visual input to drive gaze orientation due to inherent delays in processing. One solution is to make a series of reflexive catch-up saccades that correct for the developing position error. However, due to saccades having a latency of approximately 150ms when elicited during smooth pursuit (De Brouwer, Yuksel, Blohm, Missal, & Lefèvre, 2002), the eye would continually lag behind the moving object. To account for the ability of smooth ocular pursuit to match object motion (up to approximately 80 deg/s), it has been suggested that a basic predictive mechanism in the form of efference copy of the ongoing oculomotor command is required (Krauzlis & Lisberger, 1994; Krauzlis & Miles, 1996; Robinson, Gordon, & Gordon, 1986; Yasui & Young, 1975). Others subsequently extended upon this idea and showed that a more complex predictive mechanism is necessary to pursue the type of complex object motion that is experienced in our normal surrounds (Barnes, 2008; Bennett & Barnes, 2003). Indeed, rather than smooth pursuit being essentially a reflexive response to current object motion, evidence is presented below showing that smooth pursuit is influenced by expectation, attention, and prior experience.

If the velocity of the eyes does not match the target, and it is not feasible to simply increase smooth eye velocity, an individual will increase the number of saccades in order to correct for the developing position errors. These small amplitude, rapid catch-up saccades compensate for errors in predicting an evolving target motion, and are thought to be more effortful than smooth pursuit alone (Rommelse, Van der Stigchel, & Sergeant, 2008; Takarae et al., 2004a). This is because these responses are driven by sensory input rather than internally generated feedback of the accuracy of performance and predictions of target motion (Takarae et al., 2004a). Autistic individuals make a greater number of catch-up saccades, which are less accurate and associated with lower pursuit gain than typical individuals, and thought to be due to a problems in motor function (Johnson et al., 2016; Takarae et al., 2004a; Takarae, Minshew, Luna, & Sweeney, 2004b). This conclusion was based on the finding of a negative correlation between the accuracy of primary catch-up saccades and simple motor speed on a grooved peg board task and finger tapping task, thought to be due to sensorimotor difficulties (Takarae et al., 2004a). It has been suggested that an increase in saccade variability occurs due to differences in the cerebellum compared with typical individuals (Cody, Pelphrey, & Piven, 2002; Schmitt et al., 2014). This indicates that a difference in oculomotor control in autistic individuals could be due to difficulties at a functional level (Takarae et al., 2004b).

Differences in smooth pursuit have also been found consistently, with large effect sizes between autistic participants and typical controls (Johnson et al., 2016). Such differences are thought to stem from a difficulty in the transfer of visual motion information from sensory to sensorimotor systems (Takarae et al., 2004a; Takarae et al., 2004b). This has been evidenced in anticipatory smooth pursuit, where participants anticipate target motion based on cues available within the task rather than relying on the target motion itself. Autistic individuals have similar anticipatory smooth pursuit (i.e., open-loop) to typical controls but ongoing pursuit (i.e., closed-loop) has larger and more frequent saccades (Aitkin et al., 2013). These differences in smooth pursuit (e.g., lower gain in autistic individuals) have typically been examined in tasks in which the participant follows a simple, non-biological target moving on a horizontal plane (Takarae et al., 2008; Takarae, Luna, Minshew, & Sweeney, 2014; Takarae et al., 2004a; Takarae et al., 2004b, 2007).

Observing biological motion has been shown to facilitate pursuit (i.e., increased velocity gain) in typical participants when the stimulus is presented in a normal upright orientation compared to when it is inverted (de Xivry, Coppe, Lefèvre, & Missal, 2010). This suggests that the predictive mechanism underpinning smooth pursuit of biological motion receives input from a visuomotor pathway that is tuned to biological motion. Further support for this notion is shown by the finding that smooth pursuit is more accurate for biological compared to non-biological stimuli (Coppe, de Xivry, Missal, & Lefèvre, 2010). Such findings for gaze orientation are consistent with the suggestion that the action observation system is biologically tuned to respond to human movement (Gertz, Hilger, Hegele, & Fiehler, 2016), crucial for sociocognitive functioning (Press, 2011). Interestingly, similar facilitation of smooth pursuit by biological motion has been observed in autistic participants. For example, when asked to pursue a red dot within a green bird (moving horizontally) that becomes occluded, autistic participants pursued with similar gain values to typical controls (Ego et al., 2016). In addition, autistic participants had a similar predictive recovery, which is the tendency to increase eye velocity prior to the reappearance of the target. Finally, the number of saccades made during target blanking was similar to controls, as was position error in respect to the reappearance of the target (Ego et al., 2016). This suggests that the underlying mechanisms that drive pursuit (e.g., internal models about target and eye motions) are intact in autistic individuals (Aitkin et al., 2013; Ego et al., 2016), and can be facilitated by biological motion.

Even when observing non-biological stimuli, individuals can improve smooth pursuit in a small number of trials if the target motion is predictable (Barnes, 2008; Bennett & Barnes, 2003). Similarly, it has been suggested that experience of a movement improves accuracy of pursuit, with experts in dance having shorter fixation and saccade durations than novices when watching a contemporary dance film (Stevens et al., 2010). This is due to experts having developed sensorimotor representations of the observed movement and comparing of observed kinematics to previously experienced movements (Gertz et al., 2016; Gidley Larson & Mostofsky, 2008; Mostofsky et al., 2006). The role that the motor system has, and the sensorimotor representations it contains, has been investigated with transcranial magnetic stimulation (TMS). The time to first fixation on the area of interest (i.e. the area around the limb; hand or leg) was disrupted when TMS was applied over motor areas that are associated with the observed action. Time to first fixation is a measure that is indicative of predictive gaze observation, and depends on the retrieval of sensorimotor representations involved in movement prediction (Elsner et al., 2013). Similarly, when observing grasping actions, TMS applied over the hand region of the motor cortex disrupts processing of the representation of the hand grasping actions, thereby impacting upon predictive pursuit eye movements (Elsner et al., 2013).

Further evidence suggesting that repeated exposure and more movement-related experience enhances pursuit has been found in with gymnasts who have higher pursuit gain compared with non-athletes. This was said to be a function of their training, which includes complex rotational movements. Specifically, Olympic level, second-tier international competitors, state junior gymnasts, and non-athletes observed sinusoidal horizontal visual stimuli with maximum velocities of 60, 120, 140, 160 °/s, chosen to represent the predictable pursuit requirements in common gymnastics routines (von Lassberg et al., 2012). Those with the most experience exhibited higher pursuit gain values, whereas the amateurs and non-gymnasts exhibited lower values. Interestingly, there was a significant decrease in pursuit gain values after a three week break from gymnastics training, which emphasises the influence of continual practice of complex multiaxial rotational movements (von Lassberg et al., 2012). Similar to this, sinusoidal gymnastics actions were investigated in *Chapter Four* of the current thesis in order to determine the effect of experience of these movements on preferential attention in autistic adults. To recap, it was found that those with experience exhibited different gaze behaviour to those without experience, in which, for Twists, the trampolining group orientated towards the incongruent model first, but the congruent model for longer in their first fixation, and the non-trampolining group exhibited no significant difference in attention to either model, and then the opposite behaviour for *First Fixation Duration* in that they fixated longer on the incongruent model in their first fixation. This difference in gaze behaviour was likely due to the experienced participants having developed sensorimotor representations that enabled them to identify the observed movements more efficiently.

If autistic individuals can predict the action from previous experience, their eye movements in relation to known stimuli should be similar to what would be expected from typical controls (Aitkin et al., 2013; Falck-Ytter, 2010). However, this could be offset by the finding that autistic individuals have a stronger association between self-generated motor commands and proprioceptive feedback than typical individuals do in a motor task. This is demonstrated alongside a greater activation in cortical areas associated with the intrinsic coordinates of motion (M1, somatosensory cortex), and less activation in those areas associated with representations of extrinsic coordinates (premotor, posterior parietal), to which the somatosensory connections to the intrinsic areas are thought to be over-expressed (Haswell et al., 2009). These difficulties result in reduced visual attention to the features of actions, such as the goal or the limb used to execute the action (Marsh, Pearson, Ropar, & Hamilton, 2015).

To expand upon *Chapter Four* and *Five* where differences were found in preferential viewing (i.e., *First Fixation Location* and *Duration*), the current study will examine pursuit of known movements. As described above, it is suggested that autistic individuals have oculomotor difficulties that result in poor pursuit performance, but there is some equivocality within the literature (Aitkin et al., 2013; Johnson et al., 2016; Takarae et al., 2008; Takarae et al., 2004a; Takarae et al., 2007). This could stem from the use of non-biological motion stimuli and/or differences in experience of the observed movement (von Lassberg et al., 2012). Here, then, a group of autistic participants with trampolining experience and a group without will be compared when pursuing a point-light depicting trampolining actions.

Method

Participants

The original sample of 43 participants, comprised of 6 females, with an age range of 21-61 years (*M* = 36.83, *SD* = 13.42), and 37 males with an age range of 19-61 years (*M* = 35.57, *SD* = 13.05). However, 22 participants were removed from the study due to issues with their attention span and/or behavioural problems (e.g., turning off equipment, leaving during collection, or not looking at the screen), which resulted in poor quality of data. This left a total of 21 participants, with an age range of 19–61 years (*M* = 35.19, *SD* = 13.57), consisting of 3 females, with an age range of 26-28 years (*M* = 27.33, *SD* = 1.15), and 19 males with an age range of 19-61 years (*M* = 36.50, *SD* = 14.28). These participants were allocated to two groups according to their trampolining experience. The trampolining group (n = 13) with an average of 122 hours of experience and an age range of 21–61 years (*M* = 35.76, *SD* = 13.84), comprised of 3 females, with an age range of 26-28 years (*M* = 27.33, *SD* = 1.15), and 10 males with an age range of 23-61 years (*M* = 38.20, *SD* = 14.08). The non-trampolining group (n = 8) comprised of all males with an age range of 19-46 years (*M* = 30.00, *SD* = 10.20).

This was an opportunity sample, using individuals in two different sites, namely the drill centre (trampolining centre) in the AutismAbility project (for the trampolining group) and in the Social Enterprise and Gallagher House at Autism Together (for the non-trampolining group). Participants had normal or corrected-to-normal vision and were screened via their person-centred plans for the following exclusion criteria: dyspraxia, dyslexia, epilepsy, and other neurological or psychiatric conditions. Sample characteristics are presented in Table 26.

Participants were approached by the researcher, their support worker, or the group lead to establish their willingness to participate. The researchers were clear that the personal interests of the participants were of the utmost importance, with all invited participants allowed as much time as necessary to make a decision regarding their involvement in the study. Where possible, consent was obtained from the participants. However, in certain cases it was necessary to refer to the Mental Capacity Act (2005) to establish a participant's capacity to make a decision. This process was facilitated by one-to-one support workers, group leads, and activity leaders. Once the capacity to consent to participate was established, all necessary measures were completed for each participant before starting the protocol. The experiment received clearance from the Liverpool John Moores University ethics committee.

Stimuli

The stimuli used for this study is the same as outlined in *Chapter Four*, with two trampolining actions (Straight Jumps and Seatdrops) demonstrated by point-light displays of the autistic model. A single point-light display of the autistic model was shown in the centre of the screen for 5 seconds. The Straight Jumps trail consisted of the autistic model demonstrating four bounces (B, B, B, B), and the Seatdrops trial consisted of the autistic model demonstrating two bounces, a Seatdrop, and a further bounce (B, B, SD, B). This was chosen as a way to investigate whether the participants could anticipate when the model was going to do the Seatdrop. Data validity (gaze sample percentage) ranging from 29-97 in the trampolining group (M = 67.59), and 50-99 in the non-trampolining group (M = 71.00).

Table 26. *Participant Demographics.*

		Trampolining Group Mean (*SD*)	Non-trampolining Group Mean (*SD*)
n		13	8
	Gender	3 females	0 females
VIQ		49 (22)	58 (27)
	Age Equivalent	7 years 6 months	9 years 8 months
SRS	*t*-score	70 (10)	64 (14)
	AWR	65 (14)	64 (13)
	COG	73 (7)	65 (18)
	COM	67 (10)	63 (13)
	MOT	61 (10)	54 (6)
	RRB	74 (7)	66 (12)
	SCI	68 (10)	62 (12)
SP	Seeking	39 (11)	30 (12)
	Avoiding	55 (13)	33 (9)
	Sensitivity	45 (13)	45 (13)
	Registration	46 (12)	35 (16)
	Auditory	23 (6)	15 (7)
	Visual	14 (5)	7 (5)
	Touch	24 (5)	14 (4)
	Movement	16 (6)	14 (7)
	Body Position	12 (4)	11 (5)
	Oral	17 (8)	14 (12)
	Conduct	18 (8)	16 (8)
	Social Emotional	42 (11)	25 (6)
	Attentional	27 (8)	20 (7)
MABC	Total Test	7 (5)	7 (6)
	Manual Dexterity	8 (7)	10 (8)
	Aiming & Catching	9 (5)	7 (5)
	Balance	5 (3)	5 (4)

VIQ – Verbal IQ, measured by the Peabody Picture Vocabulary Test (fourth edition)

SRS – Social Responsiveness Scale (second edition)

SP – Sensory Profile (second edition)

MABC – Movement Assessment Battery for Children (second edition).

Design

The experimental was arranged as a 2 group (trampolining or non-trampolining) x 2 stimulus (Straight Jumps and Seatdrops) design. Trampolining experience was the between-participants factor (determined by the number of hours of trampolining experience), whereas the stimulus was a repeated measure. To quantify gaze-orientation behaviour, the following dependent variables were analysed in each of the eight trials: sum duration, average duration, and count of each eye movement (saccade, fixation, unclassified); saccadic amplitude in degrees (sum and average).

Procedure

The researcher sat at a right angle to the participant in front of a laptop that was used to run the protocols and the eye-tracker (tobii X2-60). Participants sat in front of a 20-inch LCD screen (1600 x 900 resolution, 75Hz refresh rate) that acted as the external screen to which the eye-tracker unit was mounted. Across participants, the viewing distance ranged from 45-100cm. Eye movement behaviour was recorded while participants watched the point-light displays. Participants were asked to stay seated and told that they could move in the seat once calibration was complete. This was particularly important for participants who have repetitive behaviours such as rocking. Participants were calibrated using a two-point calibration template. Once the error vectors were minimal, the experiment was then started.

Participants were told verbally by the researcher that there were eight videos and asked to follow the person on the screen depicted by the point-light display, as with *Chapters Four* and *Five*, participants were not told what to expect in terms of model or action. These instructions were printed on the screen at the start of the experiment to remind participants. This simple instruction was chosen so behaviour could be as natural as possible. One point-light display was shown at a time, demonstrating an action for five seconds), examples of such can be found in Figure 22 and 23. This shorter duration demonstration was adapted from previous studies (*Chapter Four* and *Five*) and was intended to maintain participants attention for as long as possible and maximise the amount of eye movements recorded. This made the experiment more inclusive to participants who had difficulty maintaining concentration for the duration of the previous studies.

Between trials, the trial number appeared in the centre of the screen for 2 seconds; this centred the participants gaze to a neutral position and gave them a sense of how long was left of the study. This was based on positive feedback from staff at Autism Together for the *Recognition Study* in *Chapter Five*. There were six Seatdrops trials (experimental trials) and two Straight Jumps trials (catch trials). These were presented in a pseudo-random order, with a total experiment time of 3 minutes.

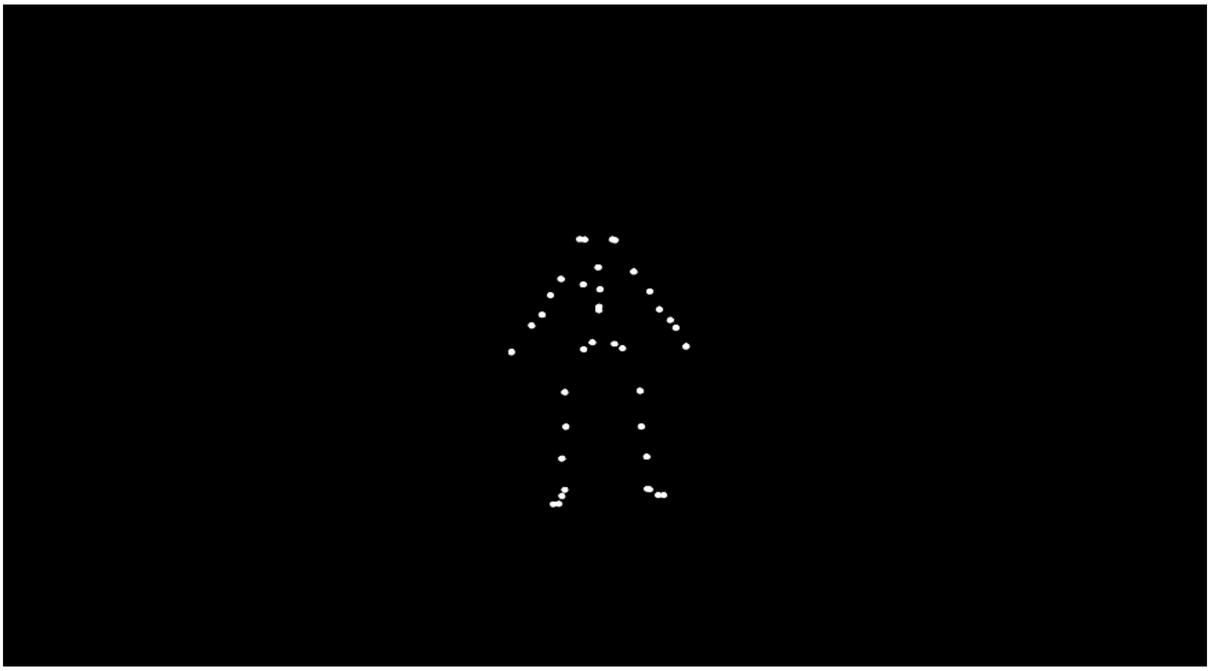

Figure 22. Point-light display of the Straight Jumps trial used in Pursuit Protocol.

Figure 23. Point-light display of the Seatdrops trial used in Pursuit Protocol.

Data Analysis

The tobii I-VT fixation filter was used, with the tobii I-VT (Attention) parameters set with the I-VT fixation classifier threshold of 100 degrees/second instead of the default of 30 degrees/second. Pilot work revealed that using the default parameters leads to a large proportion of smooth pursuit data being wrongly classified as saccades, when the eye is moving in order to stabilise the fovea onto the target. Specifically, with the default velocity threshold for a fixation, smooth pursuit eye movements would be incorrectly classified as a series of saccades if the eye moved at more than 30 degrees/second to track the point-light display. Increasing this value to 100 degrees/second meant that these movements were correctly classified as moving fixations and not saccades. Gaze behaviour data was exported from tobii Studio for each participant, and then ran through a MATLAB routine, which was created to use the GazeEventType, which classifies eye movements into saccades, fixations, and unclassified. The duration of these events was also exported in frames, and later converted to milliseconds.

Intra-participant mean data was calculated for the two different stimuli types (Straight Jumps and Seatdrops) for all dependent variables (sum, average, and count) for each eye movement (saccade, fixation, unclassified); saccadic amplitude in degrees (sum and average). These were then submitted to separate 2 Group (trampolining; non-trampolining group) x 2 Stimuli (Straight Jumps; Seatdrops) mixed factor ANOVA. Alpha was set at $p < 0.05$, and partial eta-squared (η_p^2) expressed the size of the effect. Significant interactions effects were decomposed using the multiple *t*-tests for which Type I error was control (Alpha was set to $p < 0.01$).

The video clips of the point-light displays were manually digitised in Kinovea (2019) (version 0.8.15). The sternum marker was tracked on a frame-by-frame basis in order to provide position data that could be qualitatively compared to participant's gaze position data. This comparison was deemed important as it enabled a qualitative description of the similarity in the stimulus (i.e., sternum) and eye position trajectories (i.e., amplitude and timing), and thus the overall quality with which participants were tracking the target during trials.

Results

Means and standard deviations are presented in Table 27 for the trampolining and non-trampolining groups for all dependent variables. These data show that both groups made a similar number of saccadic and fixational eye movements, with a similar duration.

The gaze position data in the vertical axis for the trampolining and non-trampolining group was averaged to give a grand mean gaze position plot in the Straight Jumps and Seatdrops trials. These mean plots along with standard deviation areas can be seen in Figure 24a and 24b.

The position data for the sternum marker (blue line) from the digitised point-light display is plotted on a secondary axis for comparison. As can be seen from Figure 24a and 24b, the trampolining and non-trampolining group track the point-light display as it moves vertically on the screen in the Straight Jumps and Seatdrops trial. As expected, there was some inter-participant variability in the groups (shown by the standard deviation areas), but nonetheless the general pattern was for groups to track the point-light display with similar amplitude and timing.

This qualitative similarity between the groups was quantified using 2 group (trampolining or non-trampolining) x 2 stimulus (Straight Jumps and Seatdrops) mixed factor ANOVAs. There was no significant difference found in total duration of: i) saccades [stimuli, F (1, 16) = 1.04, $p > 0.05$, $\eta p^2 = 0.06$; group, F (1, 16) = 0.43, $p > 0.05$, $\eta p^2 = 0.03$; interaction, F (1, 16) = 0.03, $p > 0.05$, $\eta p^2 = 0.00$]; ii) fixation [stimuli, F (1, 16) = 1.49, $p > 0.05$, $\eta p^2 = 0.09$; group, F (1, 16) = 0.79, $p > 0.05$, $\eta p^2 = 0.05$; interaction, F (1, 16) = 0.67, $p > 0.05$, $\eta p^2 = 0.04$]; iii) unclassified eye movement [stimuli, F (1, 16) = 0.06, $p > 0.05$, $\eta p^2 = 0.00$; group, F (1, 16) = 0.89, $p > 0.05$, $\eta p^2 = 0.05$; interaction, F (1, 16) = 0.57, $p > 0.05$, $\eta p^2 = 0.04$].

There was no significant difference found in the average duration of: i) saccades [stimuli, F (1, 16) = 1.20, $p > 0.05$, $\eta p^2 = 0.07$; group, F (1, 16) = 2.17, $p > 0.05$, $\eta p^2 = 0.12$; interaction, F (1, 16) = 0.63, $p > 0.05$, $\eta p^2 = 0.04$]; ii) fixations [stimuli, F (1, 16) = 1.60, $p > 0.05$, $\eta p^2 = 0.09$; group, F (1, 16) = 0.76, $p > 0.05$, $\eta p^2 = 0.05$; interaction, F (1, 16) = 2.52, $p > 0.05$, $\eta p^2 = 0.14$]; iii) unclassified eye movement [stimuli, F (1, 16) = 0.00, $p > 0.05$, $\eta p^2 = 0.00$; group, F (1, 16) = 0.54, $p > 0.05$, $\eta p^2 = 0.03$; interaction, F (1, 16) = 0.39, $p > 0.05$, $\eta p^2 = 0.02$].

There was no significant difference found in the count of: i) saccades [stimuli, F (1, 16) = 1.41, $p > 0.05$, $\eta p^2 = 0.08$; group, F (1, 16) = 0.12, $p > 0.05$, $\eta p^2 = 0.01$; interaction, F (1, 16)

= 0.03, $p > 0.05$, $\eta p^2 = 0.00$]; ii) fixations [stimuli, F (1, 16) = 2.49, $p > 0.05$, $\eta p^2 = 0.13$; group, F (1, 16) = 0.04, $p > 0.05$, $\eta p^2 = 0.00$; interaction, F (1, 16) = 0.73, $p > 0.05$, $\eta p^2 = 0.04$]; iii) unclassified eye movement [stimuli, F (1, 16) = 0.86, $p > 0.05$, $\eta p^2 = 0.05$; group, F (1, 16) = 0.43, $p > 0.05$, $\eta p^2 = 0.03$; interaction, F (1, 16) = 0.00, $p > 0.05$, $\eta p^2 = 0.00$].

For saccadic amplitude, there was no significant difference for the sum of all amplitudes [stimuli, F (1, 16) = 0.00, $p > 0.05$, $\eta p^2 = 0.00$; group, F (1, 16) = 0.00, $p > 0.05$, $\eta p^2 = 0.00$; interaction, F (1, 16) = 0.44, $p > 0.05$, $\eta p^2 = 0.06$], or for the average of all amplitudes [stimuli, F (1, 16) = 0.02, $p > 0.05$, $\eta p^2 = 0.00$; group, F (1, 16) = 0.00, $p > 0.05$, $\eta p^2 = 0.00$; interaction, F (1, 16) = 1.09, $p > 0.05$, $\eta p^2 = 0.03$].

Saccades tended to be small and have shorter duration, which is reflective of catch-up saccades, and periods of fixation were much longer and represent the majority of the trial. Unclassified events were short, thus supporting the fixation data in showing that participants tended to pursue the model, reinforced by the qualitative analysis of the gaze position data.

Table 27. *Means and standard deviations for the trampolining and non-trampolining group on saccade, fixations, and unclassified eye movements, with average and total duration (ms), and count (number of).*

		Trampolining Group		Non-trampolining Group	
		Straight Jumps	Seatdrops	Straight Jumps	Seatdrops
Saccade	Average Duration	29.18 (7.87)	29.77 (7.08)	23.58 (5.61)	27.32 (6.41)
	Total Duration	321.97 (265.71)	396.09 (476.80)	204.76 (219.42)	308.93 (432.59)
	Count	9.86 (6.93)	11.74 (10.87)	8.07 (9.14)	10.56 (12.39)
Fixation	Average Duration	1013.32 (912.70)	1101.12 (1035.07)	1874.34 (1850.10)	1091.12 (761.89)
	Total Duration	4409.85 (766.90)	4340.66 (664.79)	4810.72 (523.54)	4460.12 (808.14)
	Count	7.64 (4.22)	8.07 (4.46)	6.64 (5.75)	8.12 (6.83)
Unclassified	Average Duration	231.94 (507.06)	160.47 (208.02)	79.83 (108.22)	158.26 (273.12)
	Total Duration	564.39 (580.72)	481.52 (356.96)	283.34 (363.97)	442.07 (575.98)
	Count	4.05 (3.58)	5.41 (6.62)	2.79 (3.03)	4.17 (5.53)
Amplitude	Average	3.72 (3.27)	3.27 (2.14)	3.30 (2.39)	3.74 (2.14)
	Total	29.58 (24.53)	24.00 (18.38)	24.11 (19.66)	28.38 (23.49)

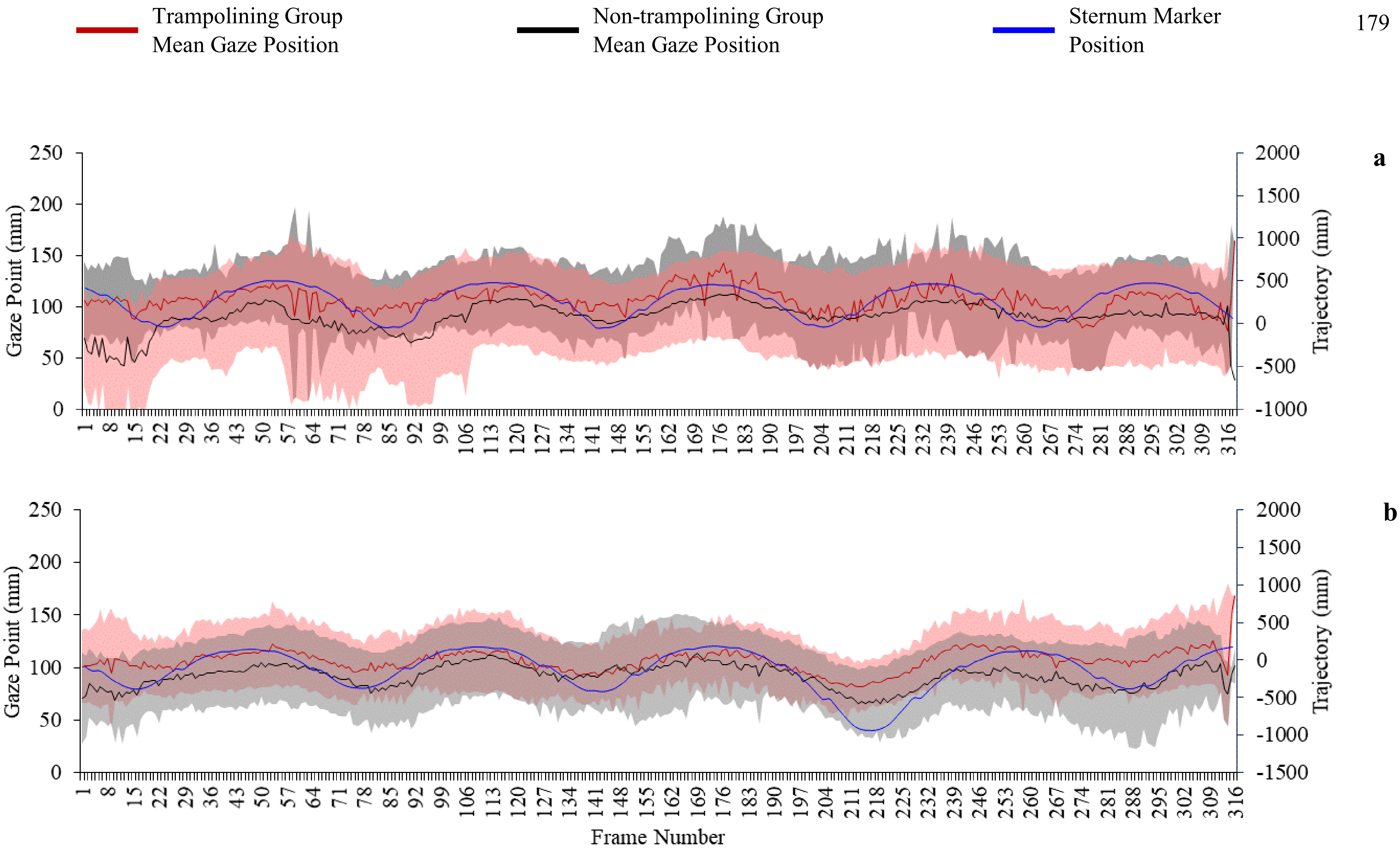

Figure 24. *Mean gaze position data for the Straight Jumps trials (a) and the Seatdrops trials (b), with the trampolining (red line) and non-trampolining (black line) groups, marker position (blue line), and standard deviation areas (trampolining – red area, non-trampolining – grey).*

Discussion

It has been suggested that autistic individuals tend to respond reflexively to sensory input rather than using feedback from past performance and predictions of target motion (Takarae et al., 2004a). This results in more catch-up saccades, and lower pursuit gain than typical individuals when pursuing non-biological targets (Johnson et al., 2016; Takarae et al., 2008, 2014; Takarae et al., 2004a; Takarae et al., 2004b, 2007). That said, it has been shown that biological motion facilitates pursuit in typical control participants, with the predictive mechanism that underpins smooth pursuit being attuned to biological movement (Coppe et al., 2010; de Xivry et al., 2010). Similarly, when autistic individuals pursue biological motion they have comparable pursuit gain, predictive recovery, and number of saccades to typical controls (Ego et al., 2016). Pursuit in typical controls is also enhanced by experience, with experienced individuals exhibiting higher pursuit gain than novices (Stevens et al., 2010; von Lassberg et al., 2012). This is due to the use of sensorimotor representations that help predict how the observed movement will progress (Gertz et al., 2016; Gidley Larson & Mostofsky, 2008; Mostofsky et al., 2006). However, this facilitation could be offset in autistic individuals due to a stronger reliance on proprioceptive feedback, resulting in reduced visual attention to the features of observed actions (Haswell et al., 2009; Marsh et al., 2015). The aim of the current study, therefore, was to investigate if autistic individuals with different amounts of task-specific experience (i.e., trampolining, media, drama, I.T, art) exhibit different oculomotor behaviour when observing point-light displays depicting two different trampolining actions. A secondary aim of this study was to determine if oculomotor behaviour when pursuing the trampolining stimuli could help corroborate the effects of previous chapters. The finding of no significant difference in pursuit between the groups would indicate that although having sensorimotor experience of the observed movement impacts upon how attention is initially directed (i.e., *First Fixation Location* and *Duration* in preferential viewing protocol), it does not influence the ability to track the target after that point (i.e., *Percentage of Total Fixation Duration*).

Differences in gaze behaviour between the trampolining group (who had experience of the movement) and the non-trampolining group (who did not have experience) was analysed using the gaze position data. Qualitatively, it can be seen in Figure 24 that although variable, participants were able to pursue the Straight Jumps and Seatdrops movements. There were no obvious differences between the trampolining and non-trampolining groups, thus providing a first indication that pursuit was not enhanced by experience of the observed movements. Subsequent quantitative analysis indicated there was no difference between the trampolining and non-trampolining groups in the total duration, average duration, or number of saccades, fixations or unclassified eye movements. There was also no group difference in saccadic amplitude. These data indicate that the more developed representations and greater sensorimotor experience of the trampolining group did not facilitate pursuit of the observed model movements.

A possible explanation for the groups exhibiting similar tracking behaviour could be that the use of representations to predict the observed model did not convey a particular advantage because the movements were not sufficiently complex. Although involving specialist trampolining movements, the motion was relatively slow and cyclical, and thus could be adequately predicted without prior task experience. Also, this type of motion is not unusual in our normal surrounds, where objects fall under gravity and then rebound from a surface (e.g., tennis ball). That said, although the representations that the trampolining group had developed through practice did not facilitate pursuit, they may have underpinned identification of the movement. This is consistent with the findings of *Chapter Four* where it was found that there was a difference in the *First Fixation Location* and *Duration* between the trampolining and non-trampolining groups, and no significant difference between the groups for the *Percentage of Total Fixation Duration*.

The previous study in *Chapter Five* demonstrated that autistic participant's attention is drawn to autistic kinematics. This was possibly due to a strong association between self-generated motor commands and atypical kinematics in autistic individuals (Cook et al., 2013; Haswell et al., 2009). Haswell et al. (2009) found that when autistic individuals learn a motor task they generalise only in intrinsic coordinates, resulting in a representation that has intrinsic coordinates that are double the strength of the intrinsic coordinates used by typical individuals (Haswell et al., 2009). This means that autistic individuals have a strong reliance on proprioception, which impacts upon learning through observation by downplaying the reliance on visual consequences of the action (Haswell et al., 2009). A further implication of less reliance on visual consequences is that autistic individuals are slow to adapt to motion during eye movement tasks, resulting in large variability in saccade amplitudes (Johnson, Rinehart, White, Millist, & Fielding, 2013; Mosconi et al., 2013).

From the gaze position graphs, it can be suggested that the participants in this study did not exhibit a particular difficulty tracking the target. The gaze position of the two groups seemingly followed the target position, with no significant quantifiable difference between the eye movements used in the trampolining and non-trampolining groups. This is important because a difficulty in tracking a moving target would have implications for visual processing and the associated coding of representations into motor commands for action execution (Gidley Larson & Mostofsky, 2008; Mostofsky et al., 2006). Also, the finding that participants were in pursuit of the model for the majority of the trial indicates that they did not have difficulty orientating their attention to the relevant stimuli in this task. The implication is that irrespective of their sensorimotor experience, autistic participants in this study did not exhibit an underlying deficit in overt gaze orientation, which may have impacted upon the findings for preferential viewing in *Chapter Four* and *Five.*

Summary

In conclusion, the aim of this chapter was to investigate if autistic individuals exhibit differences in oculomotor behaviour due to having sensorimotor experience of observed movements. It was suggested that the trampolining group might have enhanced pursuit, and thereby greater opportunity for visual processing, due to having representations and sensorimotor experience of the trampolining movements that they observed. However, when observing a point-light display of an autistic model performing Straight Jumps and Seatdrops, there were no significant differences between the trampolining and non-trampolining groups in the total duration, average duration, or count of eye movements. The implication is that having sensorimotor experience of trampolining does not impact autistic individual's ability to track trampolining movements. The data presented in *Chapter Six*, demonstrates that beyond the differences found in the previous chapters, wherein *First Fixation Location* and *Duration* were different in those with sensorimotor experience of the observed movement compared to those without, there is no difference in pursuit due to sensorimotor experience.

Chapter Seven: Epilogue

Aim of Chapter

The programme of work presented in this thesis examined the central question of sensorimotor development and functionality following sensorimotor experience in autistic adults across five independent experimental chapters. In this chapter, key findings will be summarised and discussed in conjunction with the conclusions of each of the preceding chapters. In Figure 25 (see below), there is an overview of the experimental design and key findings in each chapter, each vertical panel relates to a separate chapter with number of participants, general findings, and a 'take home message'.

The arrows linking the panels illustrate the flow between the chapters and how each take home message links to the next chapter. As illustrated in the left-hand panel for *Chapter Two*, there were 71 participants, 54% of whom scored the lowest standardised score for the *Verbal IQ* (Dunn & Dunn, 2007) and 69% were classified as having a significant motor difficulty from the *Movement Assessment Battery for Children* (Henderson et al., 2007). In the *Social Responsiveness Scale*, participants were classified as moderate to severe autism with the DSM-V compatible symptoms (Constantino et al., 2003), and participants were found to have avoidant sensory processing patterns, particularly found in the auditory and touch symptoms and attentional behaviours (Dunn, 2014). Together, these scores indicate that the verbal abilities and understanding, and motor abilities are lower than participants age standard (Dunn & Dunn, 2007; Henderson et al., 2007), for which participants have social and sensory deviations from the typical standard norms. As indicated by the dashed arrow, the demographic information informed the development of protocols used across the experimental chapters.

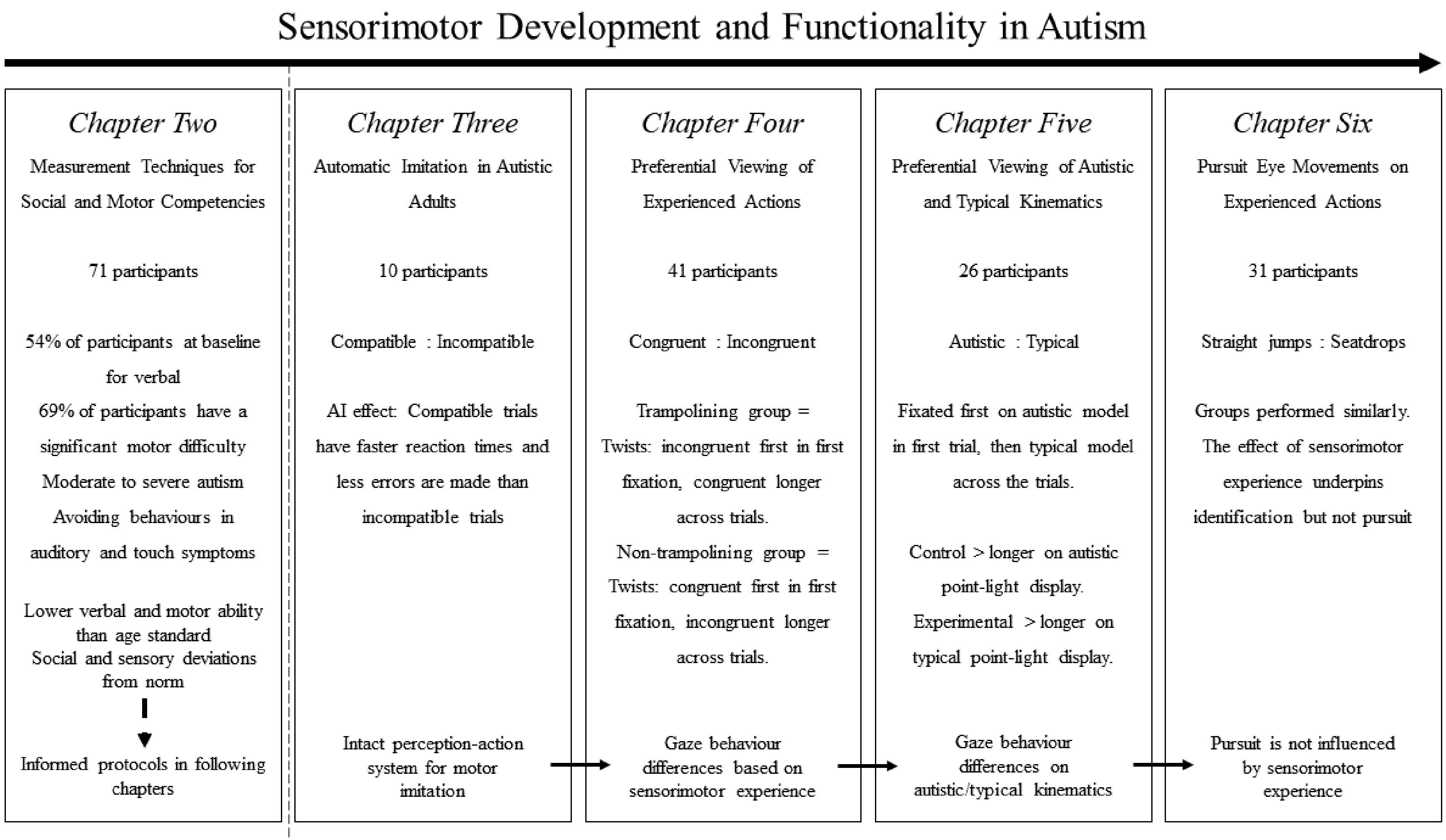

Figure 25. *Overview of experimental design and key findings for each chapter.*

For *Chapter Three*, 10 participants successfully (8 additional participants started the protocol but did not complete) completed the requisite number of compatible and incompatible trials required to examine automatic imitation. The response time data for the 10 participants indicated an automatic imitation effect (AI effect) where response times were faster for compatible (408.54 ± 15.08 ms) trials (also with less errors) compared with incompatible (464.94 ± 17.57 ms) trials. The automatic imitation effect showed that the underlying perception-action system that drives motor imitation is intact in moderate to severely autistic adults. Whilst this effect has been shown in autistic adults that require minimal support (Press et al., 2005; Sowden et al., 2016), this finding was important for the present thesis because it indicates the lower-level perception-action mechanism that processes observed biological motion into a motor action is functional in this particular group of autistic adults that are moderate to severe. Therefore, provides the platform to examine action perception following sensorimotor experience in the later chapters (indicated by the arrows in Figure 1).

In *Chapter Four*, there were 41 participants for whom preferential attention was measured as they observed congruent and incongruent point-light displays. The trampolining group (those with over 100 hours of sensorimotor experience) had a *First Fixation Location* on the incongruent model on the first trial and fixated for longer in the first fixation on the congruent model across the trials. Whereas the non-trampolining group (those without sensorimotor experience) had a *First Fixation Location* on the congruent model in the first trial and fixated for longer on the first fixation on the incongruent model across the trials. These differential preferential attentional effects indicate that a period of sensorimotor experience influences gaze behaviour when first attending to, and processing, observed actions. These findings fed into *Chapter Five* where differences in sensorimotor experience dependent preferential attention was further examined using a similar protocol that manipulated the nature of the kinematics that underpinned the modelled actions - in this chapter, the observed point-light display movements were recorded from one model that was autistic, and one model that was typical. For the 26 participants, it was found that for actions with the most experience (Straight Jumps and Gait), participants had a *First Fixation Location* on the autistic model in the first trial, with a longer *First Fixation Duration* on the autistic model across the trials. For the actions that were more specialised (Twists and Seatdrops), and the participants would likely have had less experience compared to Straight Jumps and Gait, the participants proportionally fixated first on the typical model, and proportionally fixated for longer in the total fixation duration on the typical model for the first trial and also across the trials. These findings indicate that participants demonstrated preferential attentional differences (a bias to autistic kinematics) in gaze behaviour dependent on having sensorimotor experience of autistic kinematics.

In *Chapter Six*, action perception following sensorimotor experience was examined using a pursuit protocol. Here, there were no significant differences in the tracking ability of those participants with sensorimotor experience of the actions, and those participants without the experience when pursuing an autistic model.

In the following sections of the epilogue, there will be critical evaluation of how these findings relate to the literature on the sensorimotor system in autism, and how this system develops as a function of experience. Possible future directions will also be discussed, with the intention of adding to the autism literature, which may, in future, help someone with autism.

General Summary

The aim of this doctoral research was to provide new insights into sensorimotor development and functioning in autistic adults, this was carried out by experimentally assessing preferential attention and pursuit eye movements in response to observed biological motion. In *Chapter Two*, the autistic adults who participate throughout this thesis were classified as moderate to severely autistic, with the trampolining group being more severe and exhibiting more sensory processing pattern behaviours than the non-trampolining group. Across both groups, 87% of participants could be classified as having a learning difficulty (with a standardised *Verbal IQ* score of 70 or less), and 69% of participants were classified as having a significant movement difficulty on scores derived from an assessment for aged 3-6 years old. Though motor proficiency was not significantly different between the groups for their gross motor skills.

The overall aim of the present thesis was to examine if the sensorimotor system is functional in autistic adults, to do this *the main question* of the present thesis was to investigate whether having sensorimotor experience of a movement influences how an autistic individual perceives an observed point-light model that is performing experienced movements. The observed movement was familiar because it is an action the participant has sensorimotor practice and experience of, or it could be familiar because the kinematics (e.g., autistic kinematics) are similar to that of the participant. Therefore, three studies (*Chapters Four, Five,* and *Six*) were conducted that compared autistic individuals with sensorimotor experience of the observed actions and autistic adults without this experience and investigated how perception and attention differs between the group's dependent on the level of sensorimotor experience.

In *Chapters Four* and *Five*, it was shown that autistic adults' attention was preferentially drawn to the specialised actions (*Chapter Four*: Twists, *Chapter Five*: autistic model). Whilst the underlying neural mechanisms were not examined in the present thesis, there is good evidence from fMRI studies (Calvo-Merino et al., 2005; Calvo-Merino et al., 2006) that indicates the action-observation network (Hamilton, Brindley, & Frith, 2007), which controls the processing of biological motion across a number of motor and social domains (Bolis &

Schilbach, 2018; Cook, 2016; Hannant et al., 2016b; Klin et al., 2009; Vivanti & Rogers, 2011), develops (i.e., neural plasticity; Bölte et al., 2015) based on the specificity of action-experience. For example, in an fMRI (Calvo-Merino et al., 2005) study that examined brain activity in the action-observation network of observers with different forms of motor experience (either ballet or capoeira) there was greater bilateral activation in the premotor cortex, intraparietal sulcus, right superior parietal lobe and left posterior superior temporal sulcus when expert dancers viewed movements they were trained in (e.g., ballet) compared to when they viewed movements they were not trained in (e.g., capoeira). These brain areas are suggested to correspond to activity that underpins motor simulation and action execution following action observation (Abreu et al., 2012; Buccino et al., 2001; Eaves, Haythornthwaite, & Vogt, 2014; Elsner et al., 2013; Maranesi, Livi, Fogassi, Rizzolatti, & Bonini, 2014). Therefore, and based on the aforementioned fMRI data, it is reasonable to suggest that the differential preferential viewing (attentional bias and processing) effects found the autistic adults indicates the underlying perception-action system that processes observation biological motion seems to develop (or is intact) in an experience dependent manner.

Chapter Two

The aim in *Chapter Two* was to use various measurement techniques to provide quantifiable demographic scores for the participants, to aid clarity of the volunteers, to support cross-study comparison, and to facilitate the methods being replicated. To do this, measures of verbal intelligence (Dunn & Dunn, 2007), social responsiveness (Constantino et al., 2003), sensory processing patterns (Dunn, 2014), and motor proficiency (Henderson et al., 2007) were used. These measures were used in combination because symptoms of autism vary on a spectrum from being similar to a typical individual to being severely autistic (Baron-Cohen, 2001; Constantino & Charman, 2016; Happé & Frith, 2006; Tate, 2014). This omits the arbitrary nature of discrete categories (Likert scales and small number of observations being used to categorise individuals using cut off scores), which are used to express the variability and heterogeneity seen in the autistic population. For example, it is thought that 30% of autistic individuals are minimally verbal (Tager-Flusberg & Kasari, 2013), however, the current sample that volunteered for the thesis studies was 69% minimally verbal. Regarding the large previous literature base published on autism, participants followed what would have been expected in their verbal intelligence, social skills, sensory processing, and motor ability (Deschrijver et al., 2017a; Liu & Breslin, 2013; Tager-Flusberg et al., 2005; Weiss et al., 2013). For *Verbal Intelligence*, the sample was below what would be expected developmentally for their age (Dunn & Dunn, 2007; Krasileva et al., 2017), with an average chronological age standard of 3 years and 4 months for the trampolining group (actual average age: 32 years), and an average of 7 years and 6 months for the non-trampolining group (actual average age: 37 years). Eighty-seven per cent of participants met the criteria (a score of 70 or below) for an intellectual disability in the DSM-V (American Psychiatric Association, 2013). Of which a large percentage of the autistic population is thought to have an intellectual disability, especially in the moderate to severe individuals (Charman et al., 2011; Staples & Reid, 2010; Westendorp et al., 2011). Therefore, the participants in this sample have a lower verbal intelligence than the typical population.

For the *Social Responsiveness Scale*, the scores indicated that the individuals in this sample have a diagnosis of moderate to severe autism spectrum disorder (with the trampolining group being severe and the non-trampolining group being moderate), across the DSM-V compatible symptom scores (RRBs, trampolining: 78, non-trampolining: 66; SCI, trampolining: 76, non-trampolining: 66) and the *t*-score (trampolining: 77, non-trampolining: 66). Due to social communication and interaction being rated as severe in the trampolining group and moderate in the non-trampolining group, it would be expected that there would also be sensory processing differences, as there is a relationship between social responsiveness and sensory processing (Chan et al., 2017; Hilton et al., 2007). In the *Sensory Profile* (Dunn, 2014), individuals in the sample are thought to miss sensory cues (i.e. not register or respond to someone is calling their name) and are very routine-based (i.e. creating routines to reduce unanticipated sensory input). This helped to confirm a diagnosis of autism for the participants in this sample, the symptom behaviours found fit with a diagnosis of autism spectrum disorder (American Psychiatric Association, 2013), for persistent deficits in social communication and interactions across multiple contexts, restricted and repetitive patterns of behaviour. Though, it is thought that differences in sensory processing decrease with age (Kern et al., 2007a; Kern et al., 2007b), this has not been found in this sample, as the adults in this sample exhibited behaviours which indicate extreme sensory processing patterns that deviate from the typical norms found in Dunn (2014). However, this is likely due to the severity of this sample in comparison to the sample in Kern's studies who were mildly autistic children and adults (Kern et al., 2007a; Kern et al., 2007b). Which illustrates how research on how autism changes throughout a lifetime in individuals who are severe is lacking (Seltzer et al., 2003; Shattuck et al., 2007), and therefore that research, such as that in the present thesis, importantly adds to the literature and understanding of these individuals.

If there are difficulties in the ability to learn and perform social skills, then it would be expected that there would be difficulties in learning and performing motor skills, as the means of observation needed are the same for both (Mostofsky & Ewen, 2011). The autistic adults in this sample, aged 18-66 years completed the age 3-6 years age band of the *MABC-2* (Henderson et al., 2007). In this sample, 69% of the participants were considered to have a significant motor difficulty based on completion of an aged 3-6 years measure, indicating very significant motor problems in this sample. This sample would likely have reduced independence and quality of life, as they would not be able to participate in certain activities (such as sports) and there would be an increased likelihood of accidents due to movement errors and control difficulties, which would negatively impact on their adaptive behaviour skills and daily living skills (MacDonald et al., 2013).

Together the results informed the design of later experiments, adaptions were made to make to ensure protocols were accessible to participants of this severity. This included having flexible timings for experiments to account for participants who have longer processing times/delays, minimising changes to the environment for those who prefer sameness (using rooms participants are familiar with, with furniture they are used to, not changing room layouts), limiting the use of fluorescent lights in testing areas (if possible), clearing areas of items that could be distracting to participants, limiting (where possible) foot traffic through areas or activities that are considered noisy, and using equipment that the participants are used to seeing and touching or allowing participants to. The results gave an indication to the cognitive ability, and verbal understanding of the participants, for which instructions for tasks and complexity of protocols were adapted to be simpler and more inclusive of those with a lower verbal understanding.

Chapter Three

The aim was to examine whether there is an automatic imitation effect present in adults with moderate to severe autism. Participants completed a protocol modified from Brass et al. (2000) and Sowden et al. (2016). In which participants were required to observe a video of a hand either lifting an index or middle finger, which was either compatible or incompatible to the required response of lifting their index or middle finger.

There is conflicting research both for (Bird et al., 2007; Gowen, Stanley, & Miall, 2008; Press et al., 2005; Sowden et al., 2016) and against (Fan et al., 2010; McIntosh et al., 2006; Williams, Whiten, Suddendorf, & Perrett, 2001) autistic individuals being able to produce an automatic imitation effect. Those who suggest they will not produce an automatic imitation effect, suggest that this does not happen because of differences in the processing of the observed action into an executed action (Fan et al., 2010; Fishman, Keown, Lincoln, Pineda, & Müller, 2014; McIntosh et al., 2006; Williams et al., 2001), which is not explained by cognitive or motor differences (Bird et al., 2007; Smith & Bryson, 1994; Vanvuchelen et al., 2011). However, Hamilton et al. (2007) found autistic children did not perform significantly differently to typical children when imitating the goal of an adults movement (hand movements to ipsilateral, contralateral, or both targets), when imitating in a mirror fashion (hand movements to a near or far target with either the same or different hands), or when imitating in a motor planning task (grasping overhand or underhand), suggesting there is no impairment in imitation or a global mirror neuron system deficit in autism. Similarly, the autistic adults in *Chapter Three* do not exhibit an imitation deficit, they show an automatic imitation effect in which participants exhibited faster reaction times on compatible trials ($M = 408.29 \pm 26.31$ ms) than incompatible trials ($M = 461.65 \pm 27.26$ ms), and thus an automatic imitation response of 56.39 ms, which is higher than the automatic imitation response in typical controls (43 ms; Sowden et al., 2016). Interestingly, participants also made more errors on the incompatible trials ($M = 8.80 \pm 2.48$) in comparison to the compatible trials ($M = 1.90 \pm 0.64$). The observation of the compatible hand movement facilitated performance, reducing the response time (Sowden et al., 2016), due to the movement being more readily decoded from visual to motor execution because of the compatibility between the observed and executed (Yon, Gilbert, de Lange, & Press, 2018). This can be suggested because when a stimulus-response association, such as in the automatic imitation experiment set out by Brass et al. (2000), the observed action leads to activation of sensorimotor representations for action observation and action execution in motor areas (STS, IFG, IPL, premotor cortex), which then influences the execution of the action (Hale & Hamilton, 2016; Heyes, 2001, 2011).

A hyper-imitation effect was expected as autistic individuals (Brass et al., 2000; Foti et al., 2014; Spengler et al., 2010; Vivanti et al., 2017), however, there was no hyper-imitation effect found in the autistic adults in *Chapter Three*. A hyper-imitation effect is thought to reflect reduced mentalising in the autistic individuals (Spengler et al., 2010; Théoret et al., 2005), and reduced inhibition of imitating the observed action that results in faster reaction times for compatible trials (Cross & Iacoboni, 2014; Eaves et al., 2014; Heyes, 2011), therefore not finding a hyper-imitation effect, could be evidence of mentalising and inhibitory processes in this sample.

The interference effect, i.e. slower reaction times and increased number of errors for the incompatible trials (demonstrating an automatic imitation effect) confirms a functional sensorimotor system in the moderate to severely autistic adults in *Chapter Three*, which was consistently found across participants, with little variance in the reaction times (Compatible *SD*= 47.70, Incompatible *SD*= 55.56), and in the number of errors (Compatible *SD*= 2.02, Incompatible *SD*= 7.83). The results coroborate other studies in which autistic adults have been found to show an automatic imitation effect of hand movements (Bird et al., 2007), compatibility effects for facial expressions (Press, Richardson, & Bird, 2010; Schulte-Rüther et al., 2017), and action observation system activity (mu supression) during sensorimotor resonance of hand actions (Fan et al., 2010). Involuntary activation of the motor areas associated with the observed action (and therefore sub-threshold activation of associated muscles observed from the stimulus) is thought to be delayed or missing in response to emotional faces in autism (Beall, Moody, McIntosh, Hepburn, & Reed, 2008; McIntosh et al., 2006). However, these findings are the result of using a passive observation paradigm, to which it is already known that there is reduced attention to the face in autism (Jones et al., 2008; Jones & Klin, 2013; Klin & Jones, 2008; Klin et al., 2009; Schulte-Rüther et al., 2017; Sifre et al., 2018). Autistic individuals do not use social cues of the model to modulate mimicry, if autistic participants use direct gaze compared to averted gaze, they have faster reaction times in a mimicry paradigm (Forbes et al., 2017). As there is a lack of social modulation of mimcry by gaze, with neither prosocial priming (Cook & Bird, 2012), emotional facial expression mimicry (Grecucci et al., 2013), or imitation modulated by gaze (Vivanti & Dissanayake, 2014). Whereas, stimulus-response compatibility paradigms (as used in *Chapter Three*) are thought to be a pure measure of imitative performance, as there is not a reliance on abilities other than imitation (Sowden et al., 2016).

Chapter Four

The aim was to examine whether sensorimotor experience underpins task-specific visual perception (e.g., preferential attention; and processing) of experienced/learned movements. Gaze behaviour (i.e. *First Fixation Location, First Fixation Duration,* and *Percentage of Total Fixation Duration*) was measured during preferential viewing in the trampolining and non-trampolining groups while they observed trampolining actions and Gait. Previous research (Aglioti et al., 2008; Calvo-Merino et al., 2006) suggests that the trampolining group will have different gaze behaviour compared with the non-trampolining group due to having sensorimotor experience (and therefore representations of the actions).

In Twists, on the first trial the trampolining group orientated towards the incongruent model in their *First Fixation Location*. When the data was averaged across the four trials, there was a significant group x congruency interaction that indicated the trampolining group fixated for longer in their first fixation on the congruent model (196 ms compared 145 ms) and the non-trampolining group fixated for longer on the incongruent model (183ms compared to 167ms). However, there were no significant differences between the groups for *First Fixation Location* across the trials, *First Fixation Duration* on the first trial, or the *Percentage of Total Fixation Duration*.

Straight Jumps and Gait yielded no significant group differences in the first trial or the averaged trial data, which is perhaps not suprising given both groups were likley to had accured some sensorimotor experience across the developmental life span. Whereas, for Twists and Seatdrops, only the trampolining group had task-specifc sensorimotor experience (~140 hours), with Twists in particular being a very specialised action. Therefore, the trampolining group orientating to the incongruent model suggests that the accumulated sensorimotor experience of performing Twists is likely to have underpinned the specificity of preferential attention. Due to the complexity of Twists and the disruption of the global form of the incongruent model (from being inverted), the movements would require greater processing time to evaluate the action and compare it actions that have been represented in their motor repertoire (Barton et al., 2006; Spencer et al., 2016). Activation within the action observation system (STS, IFG, IPL, premotor cortex) of the trampolining group can be inferred from the group differences in gaze behaviour, as individuals experienced in an action require fewer fixations to make a decision on how an action will unfold, and therefore less time fixating, compared to non-experienced participants (Lex et al., 2015). Therefore, the longer observers fixated on a stimulus the longer they are taking to make a decision. For the trampolining group, this decision would be based on a comparison with the observed action and known/experienced actions in their action observation system. For the incongruent stimuli this would mean that it would not match with actions in their system and so they did not have to evaluate it for as long (requiring a shorter fixation duration) (Aglioti et al., 2008; Calvo-Merino et al., 2006; Klin et al., 2009), which would be why the trampolining group fixated for longer on the congruent model in their *First Fixation Duration*.

This differences in *First Fixation Location* and *First Fixation Duration* for Twists suggests that the trampolining group's preferential gaze behaviour has developed as a function of sensorimotor experience, when compared to no group differences for Straight Jumps and Gait. Differences in the task-specific visual perception, i.e. differences in preferential attention and processing which are dependent on sensorimotor experience, mean that it can be suggested that sensorimotor functionality is intact in the adults with moderate to severe autism.

Chapter Five

The aim in *Chapter Five* was to examine whether autistic adults preferentially attend to a point-light display of model displaying autistic kinematics or typical kinematics. If sensorimotor connections are bidirectional, sensory representations would propagate to motor representations and vice versa (Heyes, 2001, 2010, 2011), therefore, learning can also occur through self-observation (Cook et al., 2013; Sangrigoli et al., 2005), and autistic individuals may develop different representations to typical individuals (based on observing their own autistic kinematics) due to motor differences in autism (Ament et al., 2015; Bo, Lee, Colbert, & Shen, 2016; Gowen & Hamilton, 2013; Kaur et al., 2018; Mache & Todd, 2016; Travers et al., 2013). A preferential viewing protocol was used where point-light display models (with autistic kinematics or typical kinematics) performed Twists, Seatdrops, Straight Jumps, and Gait. Importantly, the recognition task used in *Chapter Five* verified that autistic participants were equally as capable as typical controls at discerning a model showing autistic or typical kinematics. Out of a total score of 12 correct answers, autistic participants achieved 8.25 correct answers compared to 9.65 correct answers for the typical participants. Similar to Edey, Cook, Brewer, Bird, and Press (2019), it was found that autistic participants are able to detect perceptual differences in point-light displays in a same-different judgement. Therefore, findings from the preferential viewing study were not simply a consequence of difficulties experienced by autistic participants in recognising the different point-light display models.

For the familiar actions (Straight Jumps and Gait), participants orientated their *First Fixation Location* to the autistic model in the first Straight Jumps trial. There was also a main effect of model, in that participants evaluated the autistic model for longer across the trials on the familiar actions. This provides some support for the suggestion that the autistic sensorimotor system is influenced across development via self-observed learning leading to autism specific processes. Here, then, the autistic participants' learned representations are likely to have had some visual input from observed autistic kinematics, which would underpin the location effects by being resonated via observation of the autistic model's kinematic (Cook et al., 2013; Elsner & Hommel, 2001; Pomiechowska & Csibra, 2017; Rizzolatti & Craighero, 2004; Wolpert et al., 2011; Wolpert & Flanagan, 2001). In addition to the autistic kinematics, it is likely that participants would have developed the most sensorimotor experience of Straight Jumps and Gait (these are more common everyday actions) which means the effect for Straight Jumps could been influenced by experience such that action observation network was modulated by their familiarity and proficiency with the movement (Calvo-Merino et al., 2006; Hunnius & Bekkering, 2014). This familiarity/experience effect has also been demonstrated where observers with greater motor experience show more accurate prediction of observed actions (Stapel et al., 2016), and attention is drawn more quickly to known actions based on the specificity of the perception-action coupling (Cannon et al., 2012).

For the skilled actions (Twists and Seatdrops), participants had a higher *Percentage of Total Fixation Duration* for the first trial and across the trials on the typical model. Twists and

Seatdrops were taught to the participants by coaches based on specific criteria set out by the BAGA awards system. Therefore, sensorimotor representations of these particular actions are likely to have developed with a contribution of observing the kinematics of the typical coach. This data is consistent with experience dependent differences in visual perception where infants with no motor experience but visual experience of a movement, fixate for longer on the model best fitting their strongest visual representation of the movement (de Klerk et al., 2016). This suggests that the representation of the typical coach performing Twists and Seatdrops is retrieved when observing the typical model (Aglioti et al., 2008; Calvo-Merino et al., 2005; Calvo-Merino et al., 2006). From the findings it can be suggested that there is a difference in visual attention depending on if kinematics matches that of the participant in a movement that has developed over the participants life span. The implication of this is that if a typical model is used to investigate action observation in autistic individuals, as it has been in previous studies (Deschrijver et al., 2017a; Oberman et al., 2005; Théoret et al., 2005), conclusions drawn from the action observation system not activating may have been modulated by the observed kinematics, rather than an impaired autistic perception-action system. In future, it is important to consider the nature of the model presented to autistic participants and whether it depicts kinematics that are attuned to the autistic sensorimotor system.

Chapter Six

The aim in *Chapter Six* was to examine whether moderate to severe autistic adults with sensorimotor experience of trampolining could pursue trampolining actions better than those without experience. Pursuit in typical participants is enhanced by experience, with experienced participants having a higher pursuit gain than novices (von Lassberg et al., 2012), i.e. experienced participants make fewer catch-up saccades due to better action prediction allowing for more accurate and efficient anticipation and predictive eye movements (Badler & Heinen, 2006; Elsner et al., 2013; Gray, 2002; von Lassberg et al., 2012). Therefore, the trampolining group having sensorimotor representations of the movements should be advantageous to pursuit due to having motor knowledge of how the movement will unfold and therefore giving the observer information about where to direct fixations to (Gertz et al., 2016; Gidley Larson & Mostofsky, 2008; Mostofsky et al., 2006). Which would be demonstrated in shorter fixation and saccade durations due to enhanced visual processing (Stevens et al., 2010). However, there were no significant differences between the groups for any eye movement, for the *average duration*, *total duration*, or *count*, meaning the participants performed similarly, independent of sensorimotor experience. This was supported by a qualitative analysis of gaze position data for the trampolining and non-trampolining groups against the sternum marker position on the models for both the Straight Jumps and Seatdrops trials, in which both groups tracked the point-light displays accurately.

Together with the previous chapters it can be suggested that the trampolining and non-trampolining groups directly compare the observed movement to their representations and use this information to identify the movements, shown in their initial eye movements (in *Chapter Four*); however, this does not influence their ability to track the movement past the point of identification. Therefore, the autistic participants in the sample could exhibit the reflexive responses driven by sensory input described by Takarae et al. (2004a). Which could mean that beyond the difference in first fixations (a function of sensorimotor experience), participants ability to pursue the point-light displays was not enhanced by having sensorimotor experience, rather there could have been overshadowing problems in using action prediction to accurately pursue the point-light displays (Johnson et al., 2016; Takarae et al., 2004a; Takarae et al., 2004b). It was confirmed in the qualitative analysis that participants did not have problems with accuracy, however, oculomotor control at a functional level could be the same for the trampolining and non-trampolining groups, resulting in no significant differences in the measures of pursuit used in *Chapter Six*. Qualitatively, it was found that saccades were small and short in duration which is reflective of catch-up saccades, which is indicative of the literature that autistic individuals make more catch-up saccades (Johnson et al., 2016; Takarae et al., 2008, 2014; Takarae et al., 2004a; Takarae et al., 2004b, 2007).

Investigation of Sensorimotor Functionality in Moderate to Severely Autistic Adults

In *Chapter Two* the *Movement Assessment Battery for Children* was deemed the most influential measure for the later studies in the current thesis (*Chapters Four, Five,* and *Six*), as no significant differences between the groups in the gross motor ability, as well as an intact perception-action link in *Chapter Three*, allows there to be a link between gaze behaviour differences (attentional, preferential viewing, pursuit) and sensorimotor experience rather than as a function of motor proficiency. If motor proficiency was significantly different between the groups, then their motor system could have developed differently due to not being able to physically perform the same movements (Hannant et al., 2016b; Ludolph, Plöger, Giese, & Ilg, 2017; Pomiechowska & Csibra, 2017; Stapel et al., 2016). This has been suggested in the previous literature in typical individuals, where activation in the motor-related areas is restricted to movements that are biologically possible for that individual (Gertz et al., 2016; Gredebäck & Kochukhova, 2010; Stapel et al., 2016). When participants observe biomechanically impossible finger movements, there is less activation of the inferior frontal gyrus and precentral gyri bilaterally than there is for possible movements (Costantini et al., 2005). However, when biologically impossible hand movements are observed there is significantly more activation in the posterior parietal cortex (Brodmann's areas 40 and 7) than for possible hand movements, likely due to the role this area has in sensorimotor transformations from real-world observations to body-related sensations for action execution (Costantini et al., 2005). Therefore, it can be inferred from this that participants in the trampolining or non-trampolining group should not have activation that is similar to when observing biomechanically impossible movements in their action observation system (Costantini et al., 2005). Moreover, it can be suggested from these findings that there were no differences between the groups, therefore differences found in *Chapters Four, Five,* and *Six* should be due to one group having sensorimotor experience of the trampolining movements being observed and the other group not having sensorimotor experience of the observed trampolining movements.

The inferior frontal and parietal cortices are implicated as the neural basis for the matching of observed movements with stored action representations (Iacoboni, 2009; Rizzolatti & Craighero, 2004). The potency of this matching is influenced by animacy, with the interference effect seen in automatic imitation reduced or absent when observing a model which is inanimate (Bird et al., 2007; Press, 2011; Press et al., 2005) or considered to be inanimate (Longo & Bertenthal, 2009; Tsai & Brass, 2007). This suggests that both bottom-up and top-down cues influence the degree to which observed actions are automatically imitated (Klapper, Ramsey, Wigboldus, & Cross, 2014). In *Chapters Three, Four, Five,* and *Six*, the model being observed was human, only the hand was observed to suggest this in *Chapter Three*, autistic individuals have a greater animacy bias (Bird et al., 2007; Schunke et al., 2016), therefore if a robot hand was shown or there was a suggestion that the model was inanimate, it would be expected that there would be a higher automatic imitation effect for the human hand than the robot hand in the sample of autistic adults who participated in *Chapter Three.* The anterior medial prefrontal cortex and the right temporo-parietal junction are consistently engaged in imitation inhibition (Brass, Ruby, & Spengler, 2009; Brass, Zysset, & von Cramon, 2001; Spengler et al., 2010); and when reasoning about others' mental states (Van Overwalle

& Baetens, 2009), which is associated with atypical processing of social information in autism, for whom there is different activation of these areas compared to typical controls (Castelli et al., 2002). Therefore, it would be expected that during the automatic imitation protocol in *Chapter Three*, participants would have shown index sensitivity to imitative control in the inferior frontal and parietal cortices, as well as the right temporo-parietal junction due to this area being biologically tuned to control imitative tendencies when the model is human (Klapper et al., 2014).

Automatic imitation occurs when action execution is modulated by a task irrelevant, but associated, action stimulus (Heyes, 2011). The interference indicates that the underlying sensorimotor processes are functional, as it demonstrates the extent to which action observation results in the involuntary activation of associated lower-level motor areas (Bird et al., 2007). The associative sequence learning model assumes that each action-guiding image is the compound of two representations, one containing the visual consequences of what the action looks like, and the other containing somaosensory information and motor commands of how the action feels and is executed (Brass & Heyes, 2005). Therefore the assumption is that learning can occur through self-observation, i.e. from observing one's self (Cook et al., 2013; Sangrigoli et al., 2005). In the automatic imitation protocol used in *Chapter Three*, this means that if an autistic individual participated as a model (as was collected through motion capture data for the point-light displays in *Chapters Four, Five,* and *Six*), then there may have been a greater automatic imitation effect seen in the autistic adults who participated. This could be examined in future studies with comparisons between an autistic and a typical model, and autistic and typical participants. Previously it has been found that autistic individuals have a greater automatic imitation effect than typical controls (Bird et al., 2007; Spengler et al., 2010), and actions which are most similar to human movements result in stronger motor activation in the inferior frontal gyrus (IFG) and inferior parietal cortex (IPC) (Buccino et al., 2004;

Johnson-Frey et al., 2003; Koski et al., 2002). Parietal areas are tuned to biological motion and frontal areas (such as Broca's area) are concerned with abstract aspects of action such as the goal (Brass & Heyes, 2005). Therefore, it would be expected that if an autistic individual were to observe an autistic individual performing a known or biologically possible movements (Stevens et al., 2000), then there would be greater activation in these areas for an autistic model than a typical model (Martineau et al., 2010).

Unusual movements and sensory difficulties/responsivity are associated with autism (Hannant et al., 2016a), with a relationship between the prevalence and severity (Landa & Garrett-Mayer, 2006). Sensory feedback is fundamental to planning and executing movements (Brooks, 1983), errors in movement are continually processed and corrected in a feedforward program which predicts the sensory consequences of the movement (Wolpert et al., 2011). From this it can be suggested that problems in sensory responsivity would influence the acquisition and modification of a stored motor command, leading to inflexibility and inaccuracy in executing actions (Hannant et al., 2016a; Hannant et al., 2016b). This means that the models used in *Chapter Five*, would be executing the actions differently (both the trampolining actions and gait) even though both individuals were taught the trampolining actions by the same typical coach. The typical model would be using sensory feedback at the time of the motion capture recording (later processed into point-light displays). Therefore, the autistic model would not be using this sensory feedback, so they would be executing the trampolining actions and gait in the way that they were taught, which was by the same typical coach as the autistic individuals who participated in the studies of this thesis. The autistic model should therefore be executing the trampolining actions in the same way as the autistic participants, and therefore the sensorimotor representations they have of the observed movements would match the autistic model over the typical model, resulting in greater motor resonance with the autistic observer (Abreu et al., 2012; Aglioti et al., 2008; Calvo-Merino et al., 2005; Kirsch & Cross, 2015).

Motor planning for a skilled action requires the knowledge (and appropriate storage and deployment) of how to hold and move a tool, and how to shape an effector to execute a gesture (Gowen & Hamilton, 2013). Difficulties in executing a skilled movement is referred to as dyspraxia, which is highly prevalent in autistic individuals (Dowell et al., 2009; Miller et al., 2014; Mostofsky et al., 2006), though the recognition of gestures is intact in autism (Hamilton et al., 2007), meaning the transfer of motor knowledge is where the difficulty lies (Gowen & Hamilton, 2013). The recognition of actions was investigated in *Chapter Five*, and the results concur with Hamilton et al. (2007) and Edey et al. (2019), in that autistic participants could discriminate between two models and could also recognise the actions being performed by point-light displays. The action observation network is utilised in understanding the actions of others (Pokorny et al., 2018), understanding is achieved by mapping those actions onto one's own motor system (Calvo-Merino et al., 2006). Therefore, by recognising and understanding the actions being performed by point-light displays in *Chapter Five*, the perception-action link being demonstrated as intact in *Chapter Three*, and from the group differences found in *Chapter Four*, it can be suggested that the action observation system in moderate to severely autistic adults is functional.

Examination of Gaze Behaviour during Observation of Experienced Actions

In *Chapters Four, Five,* and *Six* it was demonstrated that sensorimotor development is intact in autism. This can be inferred due to a difference in gaze behaviour seen between the autistic adults with experience of the observed movements and the autistic adults without experience of the observed movements in their *First Fixation Location* and *Duration* seen in *Chapter Four*.

This difference in gaze behaviour dependent on sensorimotor experience was then examined further in *Chapter Five*, in which the experienced movement for the autistic adults was demonstrated by the autistic model and the movement with no experience was demonstrated by the typical model. Overall, participants exhibited a preference on the autistic model for more familiar actions, and on the typical model for the less familiar, skilled actions. Straight Jumps and Gait were considered to be fundamental movements which all participants should have sensorimotor experience of (Staples & Reid, 2010), for which there was no significant differences between the groups in *Chapter Four*.

A congruent orientation elicits early facilitation of motor area M1, with a relationship between autism severity and motor inhibition, this means that more severely autistic individuals show increased motor facilitation for incongruent stimuli (Amoruso, Finisguerra, & Urgesi, 2018). For *Chapter Four* this means that although sensorimotor experience did impact preferential viewing of congruent and incongruent stimuli, the congruent orientation being what the trampolining group has sensorimotor experience of and therefore representations which are similar. However, the orientations, independent of experience could have impacted results, with autistic individuals being drawn to incongruent stimuli (Hunnius & Bekkering, 2014), and the trampolining group being drawn to the incongruent model in their first fixation on Twists. The trampolining group is more severely autistic than the non-trampolining group (as shown in *Chapter Two* from the SRS results), together with the potential use of sensorimotor representations in the trampolining group, their severity could have been a factor in why they were drawn to the incongruent model, though this was not evidenced in the correlational data.

Twists is the most specialised and skilled trampolining movement used as stimuli in these experiments. The trampolining group could perform all of the trampolining movements shown to them, evidenced in *Chapter Two* by their BAGA award levels. The average award level of the trampolining group is three; Twists have to be demonstrated to achieve a BAGA award level three. Therefore, it would be expected that there to be strong differences between the groups when viewing these stimuli, as experts have stronger motor activation than novices when they observe movements they are trained in (Calvo-Merino et al., 2005). Action observation for experienced movements is modulated by the observer's familiarity with the movement as well as their level of proficiency, as solely visual familiarity has less impact on perception than motor familiarity (Calvo-Merino et al., 2006; Hunnius & Bekkering, 2014). For *Chapter Five* this means that motor familiarity, i.e. Straight Jumps and Gait, should have the most impact on perception compared with visual familiarity, i.e. Twists and Seatdrop. However, the findings in *Chapter Five* are not consistent with motor familiarity having more impact on perception. When looking across the trials, there was a greater proportion of attention to the typical model in the *First Fixation Location*, also a greater *Percentage of Total Fixation Durations* on the typical model in Twists and Seatdrops for the first trial and also across the trials. This means that the visual familiarity of the typical model's movements had the greatest impact on perception in Twists and Seatdrops, even though participants have motor familiarity with both of these actions. However, for these actions, participants would have more visual experience of the typical coach performing these actions than motor experience from them physically performing these actions.

There is enhanced simulation from having experience of the actions being observed (Ambrosini et al., 2012; Cannon & Woodward, 2008; Elsner, Falck-Ytter, & Gredebäck, 2012), which leads to better prediction of the visual outcome of actions (Aglioti et al., 2008), better accuracy in recognising, categorising, and recalling observed actions (Casile & Giese, 2006; Renden, Kerstens, Oudejans, & Cañal-Bruland, 2014), even without visual feedback from a new action (Casile & Giese, 2006). The current programme of work supports this, in that greater attention was drawn towards experienced movements in *Chapters Four* and *Five*. Using the evaluative measures of *First Fixation Duration* and *Percentage of Total Fixation Duration*, the longer an individual is fixating on a stimulus the longer they are evaluating it (Elsner et al., 2013; Stevens et al., 2010). In *Chapter Four,* the trampolining group showed greater attention towards the congruent (experienced) movement, (longer *First Fixation Duration*). In *Chapter Five*, this was also supported, as participants preferentially attended to the kinematics which they had the most experience of (autistic kinematics) in their first fixation on the first trial. Cook et al. (2013) found that autistic individuals move with atypical kinematics, the extent to which correlated with autism severity. Autistic individuals move with greater acceleration and velocity, and do not minimise jerk as typical controls do (Cook et al., 2013). Cook et al. (2013) discussed whether differences would be found if the action stimuli matched the kinematics generated by autistic individuals. In *Chapter Five,* the action stimuli (i.e. point-light display) used was generated with motion capture of an individual diagnosed with autism spectrum disorder for the autistic point-light display. Preferential attention differences to the autistic point-light display compared with the typical point-light display in *Chapter Five* can be used to suggest that there are methodological implications in autism research for using videos and animations of typical individuals when investigating differences and impairments in those with autism.

If the observer is unable to match the observed action to a motor representation, it is thought that the action observation system does not respond and therefore representations would not be retrieved to aid in action prediction (Oberman & Ramachandran, 2007; Oberman, Ramachandran, & Pineda, 2008). For the non-trampolining group there was not increased preferential attention to the congruent (as in the trampolining group), but to the incongruent. It can be inferred that this was because the incongruent model was the most novel out of the two (being an inverted complex movement), which was why attention was drawn there, and not having sensorimotor experience of either movements meant there was no increased identification, evaluation, or visual processing (Stevens et al., 2010; Vivanti et al., 2018).

In *Chapter Five*, participants evaluated and possibly track the model's movements differently, due to the autistic model resonating with the autistic participants and the typical model not because of motor differences in autistic individuals (Gangopadhyay & Schilbach, 2012; Kaur et al., 2018; Mache & Todd, 2016). These differences in attention and subsequent evaluation could equate to enhanced pursuit in those with experience of the observed movements. This experience would be two-fold for the trampolining group, as they have sensorimotor experience of the trampolining movements and also the autistic kinematics over the typical kinematics. Through experience, direct visual tuning from self-observation and motor contributions to perception, is thought to tune perceptual models of actions according to our own kinematics and movements (Edey et al., 2017). Therefore, autistic participants with experience of the observed actions should be able to track an autistic point-light display more accurately than autistic participants without this sensorimotor experience, due to the tuning of perceptual models through their own movements. In *Chapter Six*, this was not supported, as there were no significant differences in any eye movement metric. Which was consistent with the *Percentage of Fixation Duration*, where there were no significant main effects found between the trampolining and non-trampolining group for any of the actions in *Chapter Four*. Predictive gaze is dependent on the retrieval of sensorimotor representations for motor prediction, and is disrupted when TMS is applied over the motor cortex (Elsner et al., 2013). Sensorimotor representations allow for the comparison between observed kinematics and previously experienced movements, and if identified, can also give information such as the goal of the action (Gertz et al., 2016; Gidley Larson & Mostofsky, 2008; Mostofsky et al., 2006). Any differences between the groups may have been shown in the first fixations, as there were in *Chapters Four* and *Five*.

It can be suggested from this research that the sensorimotor system, and the adaption and development of such, is intact in autism. Though, motor proficiency is not at the developmental standard (evidenced in *Chapter Two*), it can be postulated that the action observation system functions as would be expected in the typical literature, due to differences in preferential attention dependent on sensorimotor experience (Abreu et al., 2012; Calvo-Merino et al., 2006).Therefore, the research question, does sensorimotor experience of movements in autistic adults impact the perception of them, can be answered. Evidence from these studies suggest that sensorimotor experience of movements influences perception in autistic adults.

In Sum

Each study of the current thesis contributes to the current understanding of experience dependent sensorimotor development and functioning. While the evidence put forward in *Chapters Four* and *Five* was consistent in suggesting that there are significant differences between the those with sensorimotor experience and those without this experience, along with the behavioural evidence as discussed in *Chapters Two, Three,* and *Six* it can be suggested that the sensorimotor system is functional in these autistic adults. Therefore, differences in gaze behaviour between the groups occurred as a function of sensorimotor experience of the movements. Importantly, two key themes emerged that will be discussed and appraised in relation to the current literature: sensorimotor development in autism and action observation.

Implications for Research in Sensorimotor Development and Action Observation

In the introductory chapter (*Chapter One*) a review of the current literature revealed that there is strong evidence for a functional sensorimotor system in autistic individuals that adapted as function of the period task-specific sensorimotor experience (Baraglia et al., 2015; Catmur et al., 2009). In the typical literature, it is suggested that the more physical experience an individual has of a movement, the greater the activation in the action observation network resulting in greater activation in visuomotor areas (e.g., premotor cortex; IFG and IPL) when attending to a learned action, compared to an unfamiliar action (Calvo-Merino et al., 2005; Calvo-Merino et al., 2006; Casile & Giese, 2005; Kirsch & Cross, 2015). However, there are difficulties in generating and predicting motor tasks for autistic individuals (Johnson et al., 2016; Takarae et al., 2004a; Takarae et al., 2007), the result of which is that autistic individuals tend to have more unstable balance, slower and repetitive hand and foot movements, reduced coordination of locomotor skills, impaired gait, slower and less accurate manual dexterity, and hypotonia (Fournier et al., 2010; Freitag et al., 2007; Gepner & Mestre, 2002; Gowen & Hamilton, 2013). The ability to understand and therefore predict the actions of others is suggested to be impacted by this motor system specificity (Fournier et al., 2010; Gowen & Hamilton, 2013; Ronconi et al., 2013; Takarae et al., 2004a; Takarae et al., 2007), which is thought to be evidence of a broken or impaired mirror neuron system (Deschrijver et al., 2017a; Oberman et al., 2005; Théoret et al., 2005), which might also underpin difficulties in theory of mind (Baron-Cohen, 2001; Brent, Rios, Happé, & Charman, 2004; Gallagher et al., 2000; Senju, Southgate, White, & Frith, 2009; Tager-Flusberg, 2007). Therefore, when autistic individuals with sensorimotor experience of an observed action are compared to autistic adults with no sensorimotor experience of an observed action, it would be expected from this that there would be no difference between the preferential attention and gaze behaviour between these groups of autistic individuals. However, this was not the case in *Chapters Four* and *Five*, as there were differences between the trampolining and non-trampolining groups found in *First Fixation Location* and *First Fixation Duration* in *Chapter Four*, and differences in *Chapter Five* based on the kinematics of the models which was underpinned by the sensorimotor experience participants had of the actions. Furthermore, the difficulties in the ability to predict due to motor system specificity in autism (Cook et al., 2013; Fournier et al., 2010; Gowen & Hamilton, 2013; Ronconi et al., 2013; Takarae et al., 2004a; Takarae et al., 2007), was not found in this thesis, in *Chapter Six* there was no difficulty found qualitatively (gaze position graphs, see Figure 24) or quantitatively (number and duration of eye movements, see Table 25) in pursuit of point-light displays performing trampolining actions in the trampolining or non-trampolining groups. In this doctoral research there was no evidence to suggest that the action observation/mirror neuron system is broken in autism.

Severity and processing differences were examined in *Chapter Two*, and intact perception-action processing for motor imitation was demonstrated through automatic imitation examined in *Chapter Three*. From *Chapters Two* and *Three*, it can be suggested that the only difference between the trampolining and non-trampolining groups that might influence the perception of trampolining actions is that one group has participated in trampolining sessions and had accrued sensorimotor experience of trampolining (trampolining group: over 100 hours of sensorimotor experience), and the other group has not accrued this experience (non-trampolining group). Differences in gaze behaviour in *Chapter Four* are therefore likely to be underpinned by sensorimotor experience of trampolining (that were the actions being observed by participants), which suggests that having sensorimotor experience of the observed action influenced how attention was directed towards the action (Aglioti et al., 2008; Calvo-Merino et al., 2006; Casile & Giese, 2005; Kirsch & Cross, 2015; Klin et al., 2009). Since autistic individuals are thought to rely more on proprioceptive information (Haswell et al., 2009; Mostofsky & Ewen, 2011), i.e., proprioception based on atypical kinematics (Cook et al., 2013; Heyes, 2011; Sangrigoli et al., 2005), it is likely that if only a typical model was used as stimuli, these effects are less likely to have been found due to the fact that the kinematics of a typical model would be different to the autistic participants' kinematics and therefore representations. In the present thesis, an autistic model was shown as a point-light display in all eye-tracking studies (*Chapters Four, Five, Six*), with the exception of *Chapter Five* where a typical model was shown alongside the autistic model. Therefore, because a point-light display was generated using motion capture of an autistic individual, this means that the reported negative findings suggesting parts of action observation system (i.e., mirror neuron system) are impaired in autism (Deschrijver et al., 2017a; Oberman et al., 2005; Théoret et al., 2005) could be inaccurate, or certainly influenced, by the fact that the models used in these studies displayed typical kinematics, rather than autistic kinematics. It would therefore be interesting to replicate the original seminal work on mirror neuron system processing using models that displayed autistic kinematics.

In *Chapter Five*, and consistent with Cook et al. (2013), there was an attentional effect which suggests the visual system in autism is more attuned to autistic kinematics, which would be why in *Chapter Five* (see Table 21 and Figure 17) there was a preference for the autistic model over the typical model on actions with more motor experience than visual experience This could be underpinned by the fact that autistic participants would have developed representations of movements based on self-observation, as well as performing the actions (Cook et al., 2013; Heyes, 2011; Sangrigoli et al., 2005). Therefore, having autistic representations would mean that the participants sensorimotor representations would have developed by processing observed and executed autistic kinematics, which would then be why attention was drawn to the autistic model and evaluated for longer than the typical model due to the comparison between the representation with autistic kinematics and the model with autistic kinematics (Calvo-Merino et al., 2005; Calvo-Merino et al., 2006; de Klerk et al., 2016; Heyes, 2011).

For the skilled trampolining actions, participants were taught to perform the actions in a specific way (in line with the BAGA guidelines). Imitating the typical coach also may have meant that the autistic participants have a representation that contained the typical kinematics, as motor imitation is intact in these autistic adults (see *Chapter Three*). The information needed to understand and predict can be derived from observing others for those with no motor experience of a movement but visual experience, individuals tend to fixate longer on the model best fitting their visual representation if they do not have the motor experience (de Klerk et al., 2016). Therefore, for the autistic participants, if they do not have adequate motor experience to make a prediction from observation, then they used their visual experience (and the representation from it) to predict the action based on the typical kinematics of the coach, which then was most like the typical kinematics of the typical model. *Chapter Five* also adds to the literature on sensorimotor development and the formation of internal actions models during action observation, the data presented demonstrates that that sensorimotor system in autistic individuals is attuned to autistic kinematics, and this influences the perception of autistic and typical models, which previously has not been shown, it has only been suggested that there are differences in kinematics and that this could affect the perception of them, such as if stimuli is rated as natural or unnatural (Cook et al., 2013; Cook et al., 2014a).

In the autism literature the data is mixed on pursuit, with some studies suggesting that autistic participants perform predictive eye movements similarly to typical participants (Falck-Ytter, 2010), and others suggesting that autistic individuals have reduced anticipatory behaviours which negatively impacts upon pursuit (Chambon et al., 2017; Fabbri-Destro, Cattaneo, Boria, & Rizzolatti, 2009; Schuwerk, Sodian, & Paulus, 2016). As there were no differences between the groups in pursuit in *Chapter Six*, but differences in their first fixations in *Chapter Four* and *Five* as a function of sensorimotor experience, this suggests that any advantage having sensorimotor experience of the observed movement aids in the first fixation processing but does not aid in pursuit. From *Chapter Four* it can be suggested that sensorimotor experience seems to be advantageous to the identification of known and experienced movements, but from *Chapter Six* it can be suggested that this advantage does not extend beyond this point. Following on from this study, in the future the point-light display could be digitised in a way that pursuit gain could be calculated, such that this technique would allow a researcher to quantify how accurately the participants track the point-light display could be quantified, rather than measures of pursuit as is currently in *Chapter Six*. From this, and as would be predicted from the results of *Chapter Four* and *Five*, any differences in eye behaviour might be uncovered in the initial eye movements between the groups with and without experience. Moreover, all three trampolining actions could also be used, as Twists was where the main findings were found in *Chapter Four* and *Five*. Twists was not used in *Chapter Six* due to the complexity of the movement as it does not follow the sinusoidal wave typically examined in pursuit (Takarae et al., 2008, 2014; Takarae et al., 2004a; Takarae et al., 2004b, 2007), whereas, Straight Jumps and Seatdrops do display a sinusoidal wave (von Lassberg et al., 2012) meaning that differences between the groups in the more skilled action could be assessed.

The main impact for the literature from the current program of work stems from the severity of the sample. Most research examines individuals with typical language capabilities, due to the tools being validated in the typical population being applicable (Hannant et al., 2016b; Seltzer et al., 2003; Shattuck et al., 2007; Tager-Flusberg & Kasari, 2013). Also, the more severe an individual is, the more restricted interests and repetitive behaviours they exhibit, which can include body rocking, hand flapping, head banging, and other complex body movements (Esbensen et al., 2009b; Shafer et al., 2017). This can be in response to sensory input, which could be to stimulate the vestibular system, to produce visual stimulation, to reduce the effect of sensory input (by focussing on one particular sound or movement as a distraction), to deal with stress and anxiety, or even in response to enjoyment (Bolis & Schilbach, 2018; Seltzer et al., 2003; Weitlauf et al., 2014). Included in the restricted interests and repetitive behaviours is resistance to change and a desire for routine; changing between activities can be distressing and a complete change from routine (such as holidays, Christmas, changing schools, or respite centres) can also cause anxiety (Baron-Cohen, 1996; Hannant et al., 2016b). For research, this means that these behaviours might occur because there is a difference in their routine (normal tasks replaced with experiments) and environment (due to the experiment and equipment), which could then mean that the protocol cannot be followed if it is a motor task (such as in *Chapter Three* for automatic imitation), or for an eye-tracking study (*Chapters Four, Five, Six*) that would require the individual to sit still. Therefore, an individual with severe or many restricted and repetitive behaviours, they might find it difficult to complete all of the protocol, due to the new/different sensory input from the experiment. From *Chapter Two* it can be suggested that participants would have most of their sensory processing problems with sound (auditory), which should not be a problem for any of the studies in this thesis as there are no auditory based tasks. However, it does mean that because of the high registration quadrant (i.e. not registering or responding to sound), it was important to ensure that participants understood the instructions for tasks and indicated that they were happy to progress with the protocol. It also means that if there was noise from foot traffic or from the centres that the research was collected in, this could mean that participants could lose focus or exhibit more restricted and repetitive behaviours to avoid or to regulate themselves after external noise (Bolis & Schilbach, 2018; Seltzer et al., 2003; Weitlauf et al., 2014). Participants in *Chapter Two* scored in the severe category for the Restricted Interests and

Repetitive Behaviours symptom (RRBs) of the *Social Responsiveness Scale* (Constantino et al., 2003), this means that participants would be expected to have severe RRBs in everyday social interactions. Therefore, a social interaction with a different person (i.e. a researcher), or a different type of social interaction (in an experiment situation with experiment conditions) could mean that participants could exhibit a lot of body rocking, flapping, finger tapping, and head banging during an experiment. This could mean that a participant might not be able to participate in an eye-tracking study due to not being able to be calibrated as the participant is required to sit still - this type of behaviour was evidenced in the thesis and affected the sample sizes in *Chapters Four* (n = 41), *Five* (n = 26), and *Six* (n = 31), which are much lower than the sample size of 71 in the behavioural studies in *Chapter Two*.

Daily timetables and set routines can help reduce distress and anxiety, this way the individual knows what to expect from a day/situation (White & Roberson-Nay, 2009). This rigidity and sameness can lead to rituals (physical and verbal), and rigid preferences for food, objects, and in the physical environment (such as layout of a room, presence of new people, absence of familiar people) (Howlin, 2005). Therefore, individuals with moderate and severe autism can be trickier to collaborate on research projects with because researchers are generally new people to the individual and tend to disrupt routines, which can cause distress and anxiety. The room in which the study is taking place will have been changed to accommodate the research, which can be due to bringing in equipment. For the current program of work an example of this would be moving tables around so that the researcher can sit at a right angle to the participant, which is specified in the *Peabody Picture Vocabulary Test* (Dunn & Dunn, 2007), or when using an eye-tracker so that participants are not distracted by the live viewer and can focus on the monitor which the gaze data will be recorded from (tobii pro, 2018a).

Based on the aforementioned behaviours in some moderate to severe autistic adults, and in order to provide a level of efficacy within the thesis, I spent a year in Autism Together volunteering within the organisation to understand and become familiar to the volunteers and staff. Here, I embedded myself in the routine of the sessions, so the autistic individuals in the sessions were used to seeing and interacting with me. Therefore, when I started collecting data, I was no longer a new person, and the individuals were not as anxious or distressed as I have observed when other individuals who were unfamiliar to the individuals approached them during sessions. This also meant that I observed an individual's behaviour, how they expressed anxiety and stress, what their triggers were, and what they like and do not like. By gaining these skills, I was more cognisant with the volunteers and could therefore moderate when to run the protocols, which reduced the potential of the volunteers to develop some task anxiety.

The relationships and rapport I had built with the individuals at Autism Together meant that not only was I able to seek the advice and assistance from support workers, group leads, and activity leaders, I was also able to collect point-light displays using a motion capture system with an autistic individual as a model. This individual was used to seeing me in the trampolining centre and interacting with me, they would initiate conversation and seemed to feel comfortable. They were able to watch as myself and an assistant pilot tested the Vicon Motion Systems Ltd. (2012) equipment, they were shown how the markers were attached and where, using the Plug-in-Gait marker placement, which meant that the individual knew exactly what to expect before agreeing or participating. Due to the measures that were put in place, such as encouraging the individual to observe the process of collection, meant that the stimuli (point-light display) observed by participants in the eye-tracking studies (*Chapters Four, Five,* and *Six*) should have similar kinematics to the participants as the individual should have not been stressed or anxious having known what to expect. To my knowledge, this is the first time that an autistic point-light display has been used as stimuli in an experiment, meaning this is a new method for examining sensorimotor development / functioning differences and action observation in the autism population. This meant that differences in perception could be measured between a point-light display of an autistic and typical individual in *Chapter Five*.

Wider Considerations

When studying sensorimotor development in adults with moderate to severe autism, there are several methodological and theoretical challenges to be considered. I will discuss some of these challenges and their importance for this doctoral research project. The aim is to explain the difficulties that were found during this program of work in the hope that other researchers will be able to use the adaptions that have been made here to be more inclusive and accommodating to moderate to severely autistic individuals.

Autism as a Complex Condition

Autism is a condition characterised by persistent deficits in social communication and interactions, and rigid, repetitive patterns of behaviour, interests, or activities (American Psychiatric Association, 2013). Inherently there are many comorbid conditions associated with autism, with a high prevalence of co-occurrence with intellectual disabilities, ADHD, OCD, and language difficulties (Ehlers, Gillberg, & Wing, 1999; Gillberg & Wing, 1999; Lai & Baron-Cohen, 2015; Lever & Geurts, 2016; Matson et al., 2011). All autistic individuals who participated in this doctoral research were invited to participate based on inclusion and exclusion criteria, participants had a pre-existing diagnosis of autism spectrum disorder; diagnoses were re-evaluated with the measures in *Chapter Two*. Potential participants were excluded from the research protocol if their person-centred plan revealed a co-occurring condition such as photosensitive epilepsy. This condition specifically could have been triggered by the infra-red lights on the tobii pro (2018a), potentially causing a seizure, it was of the utmost importance that this was avoided.

Differences that affect perception, such as sensory seeking behaviours were evaluated in *Chapter Two*, with a battery of tests use to assess verbal understanding (Dunn & Dunn, 2007), which would influence how information should be delivered during experiments, *Sensory Profile* (Dunn, 2014) to assess if behaviours may impact eye-tracking studies, and social responsiveness (Constantino et al., 2003) to gauge severity of autism. These measures indicated that participant's verbal understanding is below what would be developmentally expected (Dunn & Dunn, 2007), there are sensory processing differences in avoiding behaviours, particularly in auditory and touch symptoms (Dunn, 2014), and also severity is moderate to severe in the participants in this sample (Constantino et al., 2003). Therefore, protocols that are generally used to examine action observation in typical individuals or individuals with mild autism, such as fMRI (Calvo-Merino et al., 2005; Gertz et al., 2016), EEG (Deschrijver et al., 2017a; Deschrijver, Wiersema, & Brass, 2017b; Eaves et al., 2016; Oberman et al., 2005), TMS (Cole, Barraclough, & Enticott, 2018; Elsner et al., 2013), and EMG (McIntosh et al., 2006) would not be suitable for this sample. Experiments and instructions were pilot tested and adapted to ensure that the volunteers were comfortable performing the tasks, and to be inclusive to as many of these individuals as possible. Time allowance was extended, it was not expected that participants would complete the protocols in a set period, participants were given as much time as they wanted. For some testing sessions this meant that only one participant would be collected, as the participant wanted to inspect the room, the equipment, and the researcher in multiple visits before starting any tasks, which meant that there was no more time in the two hours the participants were in the centre for another to participate. This could also be due to the participant's understanding of the task; the task may have to be demonstrated or explained several times.

Examples of the adaptions made to protocols can be seen throughout this thesis, with some aspects of experiments being changed from one study to another. Such as in *Chapter Four* and *Five*, a fixation cross was used in between trials in the eye-tracking studies, however, participants benefited from the number of the trial being shown instead in the Recognition Task in *Chapter Five*. This received good feedback from support workers and activity leaders; as participants exhibited less restricted interests and repetitive behaviours than they had in previous studies. From this, the trial numbers were shown in *Chapter Six*, which resulted in higher gaze sample percentages, meaning participants viewed the stimuli for more of the trials than they had in the previous studies, increasing by as much as ~10% (from an average gaze sample of 63 to 71 in the *Chapter Four* and *Six*, respectively).

Methods in Autism Research

When conducting research, with any population, methodological aspects need to be evaluated and adjusted if necessary, whilst retaining methodological rigor. When investigating sensorimotor development, there is a wide range of possible tasks to employ in research (see Introduction). However, due to the severity and verbal ability of the individuals who participated in this doctoral research, there had to be a consideration when designing studies. Modifications were made to tasks to make them more accessible for those who were minimally verbal. This included a same/different print out used in the recognition task, where participants who could not answer verbally, could answer by pointing at the same or different symbol (supplied by the charity) or the words, or using their PECS if they preferred this.

Modifications were made to tasks to reduce anxiety and stress for participants; timings for the tasks were discovered to be an issue causing unwanted anxiety and stress. This included timing such as missing out on too much of the session the participant came out of to take part in the research. This resulted in reducing testing time down to a period of 10 minutes maximum, longer testing such as for the automatic imitation protocol (in *Chapter Three*) were split into sessions and then combined during analysis. These shorter timings resulted in more participants being able to complete testing, due to keeping their attention (due to short attention spans associated with co-morbid ADHD). The automatic imitation protocol was also modified based experience with dropouts for the *MABC* in *Chapter Two*. Unlike in the previous studies examining automatic imitation, the apparatus had to be adapted for the participants in this sample. In Press et al., (2005) movements were recorded with electromyogram (EMG), however, this was deemed too distracting and intrusive for participants. Other studies (Longo & Bertenthal, 2009; Sowden et al., 2016) use a keyboard to record reaction times, participants are required to push down two buttons of the keyboard and then lift up in response to a cue, this was also deemed too distracting with also the possibility that participants may end the experiment prematurely if they have the control over the computer. The solution to this was to design a box with only two buttons (see *Chapter Three*), this way participants will be completing the same protocol as in Sowden et al. (2016) just adapted to be less distracting, meaning more participants could take part, with a greater possibility of full data sets collected.

Point-light displays were used throughout the studies in this thesis, this stimuli does not have any facial features or non-verbal gestures (other than purely the movement) which could elicit an avoiding response (see Baron-Cohen, Wheelwright, Jolliffe, and Therese (1997)) in autistic individuals and therefore should be accessible in the investigation of action observation (Davis et al., 2017; Falck-Ytter, 2015; Klerk et al., 2014; Klin & Jones, 2008). Point-light displays show a biological entity engaging in a recognisable activity, i.e. walking (Pelphrey & Morris, 2006), which can be recognised as biological by both typical and autistic individuals (Cusack et al., 2015; Saygin, Cook, & Blakemore, 2010). This was demonstrated in the Recognition Task in *Chapter Five*, in which there was no significant difference between the scores of autistic individuals and typical individuals in discriminating between two different point-light displays (an autistic and a typical model). These models would be different due to the kinematics of the movements, when individuals with mild autism are compared to typical controls, the autistic individuals have significantly poorer motor performance in balance skills and diadochokinesis (alternating limb movements in quick succession) (Freitag et al., 2007), which increases with severity (Gepner & Mestre, 2002). For biological motion processing, the extent to which autistic individuals kinematic profile is considered to be atypical is associated with severity, as well as a bias towards perceiving biological motion as unnatural (Cook et al., 2013). This means that for the sample who participated throughout this thesis, who are more severe than samples previously discussed (Cook et al., 2013; Cusack et al., 2015; Freitag et al., 2007; Gepner & Mestre, 2002; Saygin et al., 2010), the differences between mildly autistic and typical individuals are likely to be exacerbated in severely autistic individuals (Vivanti et al., 2018). Therefore, the current program of work adds to the literature, as the methods used throughout, such as using an autistic model for a point-light display, can be used in future research to examine perceptual differences in individuals with moderate to severe autism.

Diagnosis

Discussion of how the sensorimotor system affects autistic individuals has gained a standing in the autism literature (Fournier et al., 2010; Gowen & Hamilton, 2013; Hannant et al., 2016b; Hayes et al., 2018; Shafer et al., 2017; Takarae et al., 2014), though even recently social interaction is the main focus of the literature (Bolis & Schilbach, 2018; Casartelli, Molteni, & Ronconi, 2016; Chambon et al., 2017; Constantino et al., 2017; Cook, 2016; Corbett et al., 2016; Crawford et al., 2016; Davis et al., 2017; Deschrijver et al., 2017a; Krishnan-Barman et al., 2017; Lindsay, Hounsell, & Cassiani, 2017; Nebel et al., 2016; Vivanti et al., 2017). Motor differences between those with and without autism are widely accepted, with measurable impact on social interactions, therefore how the sensorimotor system in autism functions is vital to both the social and motor sides of research. Through machine learning, it is thought that kinematic parameters could be used in the future as part a battery of tests when diagnosing an individual as autistic (Li, Sharma, Meng, Purushwalkam, & Gowen, 2017), the results in *Chapter Five* can add to the literature on this, with autistic individuals being attuned to autistic kinematics. From this it can be suggested that their representations contain autistic kinematics (Amoruso et al., 2018; Cook et al., 2013; Edey et al., 2017), due to the motor differences found in autism (Hannant et al., 2016b; Kaur et al., 2018; Mache & Todd, 2016), therefore this could be used to strengthen the kinematic parameters used in diagnoses in the future. To expand on this research, future studies could include a full kinematic analysis of an autistic and typical individual before a preferential viewing protocol, so that it can be quantified where differences between the models are and then if the attention of the participants is drawn to these differences or just a global difference between the models. This would be following on from research that suggests autistic participants do not have a sensitivity to the minimum-jerk of biological motion and spend less time attending to it (Cook, Saygin, Swain, & Blakemore, 2009; Klin et al., 2009), which correlates with the extent to which their movements are described as atypical (not minimising jerk, greater acceleration and velocity) (Cook et al., 2013). It would be expected that this future research would find that there is a global difference between the kinematic profile of the models, with the autistic model showing greater jerk, acceleration, and velocity; to which the severity of participants should correlate with their initial attention on the autistic model (Cook et al., 2013). Therefore, if this difference in kinematics and attention was quantified, this information could be used to add to the literature, but also to add to the kinematic parameters used in the machine learning (Li et al., 2017) diagnostic tools.

Conclusion

Since it was thought that the sensorimotor and action observation systems in autism were impaired (Deschrijver et al., 2017a; Oberman et al., 2005; Théoret et al., 2005), the interest in this area has increased, with debate over whether this has an effect on imitation or not (Bird et al., 2007; Hayes et al., 2016a; Heyes et al., 2005; Sowden et al., 2016; Spengler et al., 2010), and whether this means autistic individuals have a sensorimotor system attuned to their atypical kinematics (Cook et al., 2013; Fournier et al., 2010). The difference in kinematics could mean that previously when it was found that the action observation system did not respond to experienced actions (Oberman et al., 2005), there may have been no effect because stimuli with typical kinematics were used.

The present thesis examined the effect of experience on sensorimotor development in autism and investigated if there are experience dependent perceptual differences in autistic adults when they observe experienced movements. From the findings, it can be suggested that the sensorimotor system is functional in the moderate to severely autistic adults, with sensorimotor experience of an action eliciting a different *First Fixation Location* and *Duration* than an action the participant has not experienced, evidenced in *Chapter Four* when the trampolining group observed Twists. In *Chapter Five,* the difference experience has on perception was shown when participants observed familiar actions (with the most motor experience) in that participants showed a preference to an autistic model, due to the autistic model resonating with their motor experience. Whereas for the skilled action (with the most visual experience), participants exhibited a preference to a typical model. In *Chapter Six*, participants in the trampolining and non-trampolining groups tracked point-light displays performing Straight Jumps and Seatdrops similarly (not significantly different in *count, average duration, or total duration for saccades, fixations, unclassified eye movements, or saccade amplitude*), independent of sensorimotor experience of the actions. Together these findings highlight how perception changes as a function of sensorimotor experience in adults with moderate to severe autism.

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