An Investigation of Motor abilities in Adults with Autistic Spectrum Disorders:
Developing a from which to assess imitation abilities

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Abstract

An investigation of motor abilities using the Movement Assessment Battery (MABC-2) for Children showed that a sample of 10 adults with Autism Spectrum Disorders are more impaired on gross whole-body type movements compared to a control sample of 20 typically developing adults. However, the MABC-2 and the clinical kinematic assessment tool found no reliable difference between the two groups on fine motor dexterity. An imitation task was devised requiring participants to imitate movements from videos shown on screen. Participants were required to imitate shapes (a) drawn by a model and (b) drawn by a moving dot in. A 2 x 2 between subjects MANOVA was employed to determine if the correlation of the path length, time and speed of the shape produced by each participant with those produced by the model differed across group or condition. Another 2 x 2 between subjects MANOVA was used to explore if the constant or variable error of path length, time, or speed of participants differed across condition or group. There were no significant main or interaction effects. These results are discussed in relation to
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Literature Review

Autism and related Autistic Spectrum Disorders (henceforth ‘ASD’) are characterised by a triad of impairment; in communicative abilities, social interaction, and restricted repetitive and stereotyped behaviours (APA, 2000). The aspect of the autistic phenotype that receives the most attention in the research literature is the lack of interpersonal engagement and social reciprocity displayed (Rogers & Williams, 2006). Research into the social competencies of people with Autism has undoubtedly led to the exciting findings of Baron-Cohen and his colleagues about those with ASD having a deficient theory of others minds (Baron-Cohen, Leslie, & Frith, 1985). However, despite helping conceptualise the nature of the impairment such investigations do not go very far beyond rephrasing the symptoms. Theory of mind argues that in order to socially interact with one another we must have an appreciation of others internal mental states, and those with ASD simply do not have a fully developed appreciation of these states. Investigating the more primordial faculties that facilitate the understanding of others minds may yield a more fundamental understanding of the Autistic syndrome. It has been argued that an imitative deficit may lie at the epicentre of the autistic syndrome leading to, and not resulting from, a deficient theory of mind (Rogers & Pennington, 1991; Meltzoff & Gopnik, 1993; Williams, Whiten, Suddendorf, & Perrett, 2001). In order to explore this question we must first conceptualise what imitation refers to in its most typical manifestation. Then the rationale for how a deficit in this ability may be a precursor to developing a Theory of Mind will be outlined. The mirror neuron system will be put forward as a possible neurocognitive explanation for an imitative abnormality. Once the theoretical foundations have been set the empirical evidence investigating whether people with ASD have qualitatively different imitation abilities will be discussed. Finally, the rationale for the present study will be presented.

Defining Imitation

“Imitation refers to copying by an observer of a feature of the body movement of a model” (Heyes, 2001, p.254). The author of this definition further stipulates that in order for a movement to be deemed imitation there must be a specific causal link between the movement of the model and that of the observer. This excludes any instance in which an equivalent movement is produced by two people by chance. There are a number of types of copying behaviour that need to be disentangled from imitation.
For instance, mimicry refers to a spontaneous form of imitation that is automatic and rapid which may occur outside of conscious awareness (Moody & McIntosh, 2006; Sevlever & Gillis, 2010). An example of this is the tendency for an infant to copy the action of tongue protrusion when observed in an adult care giver (Meltzoff & Moore, 1977). Acts of contagion such as yawning of another operate below the level of conscious awareness and are not considered to be true imitation owing to the lack of goal-directedness in the movement (Williams, 2008).

An observer may also reproduce the outcomes of a model by means of a process known as emulation. Emulation refers to achieving the same goal or end-state as that of the model, but not necessarily modelling the specific form of the behaviours used to achieve this end-state (Rogers & Williams, 2006). For example, a model may press a button with their finger to produce a sound and an observer can reproduce the same end-goal (i.e. produce the sound) by employing a different movement (pressing the button with their elbow). The performance of emulation may be influenced by more than simply the movement of the model. For instance, placing a button in front of a participant is more likely to lead to the person pressing the button then completing another movement because the button affords pushing. Furthermore, a person may push a button because prior learning has taught them that pushing a button tends to cause an outcome. It is consequently difficult to attribute behaviour to the movement of a model independent of the end-state produced. Thus ‘true imitation’ is only achieved when both the intention and specific form of a modelled action are produced (Sevlever & Gillis, 2010).

Research investigating imitation abilities in humans rarely employs a stringent taxonomy of imitation behaviours such as that described above. Accordingly, the combinations of tasks used to investigate imitation are incredibly heterogeneous and frequently conflate varying types of copying behaviour referring to them all under the umbrella term imitation. Williams et al. (2004) group the types of imitation investigated in a more operational manner segregating imitation in terms of whether or not an object was present (actions-on-objects) or not (gestural). A further dichotomy can be drawn between actions that are symbolic and not symbolic. Symbolic actions are those that hold a semantic meaning, for instance waving your hand can be meaningfully construed as a greeting. However, despite the blurring of definitions, systematic literature reviews consistently find an imitation deficit in people with Autism (Rogers &
Pennington, 1991; Smith & Bryson, 1994; Williams, et al., 2004; Sevlever & Gillis, 2010). These will be discussed in greater detail below. This suggests that people with ASD may be impaired in many aspects of copying behaviours and not simply true imitation.

**The Correspondence problem**

When we observe another individual move in a particular way we cannot see or do not consciously know what motor commands were implemented to produce that specific movement (Brass & Heyes, 2005). Yet, we can implement a functionally equivalent motor plan and produce the same movement if we so wish. We reserve this ability even if the action observed is perceptually opaque (Heyes & Ray, 2000). This is when the movement we are producing offers limited perceptual feedback to us. For instance, when we copy somebody’s facial expression we cannot see our own face moving. This means it is not a system of visual feedback and error correction that lead to the successful performance of the act (Ramachandran & Oberman, 2006). Therefore, in order to imitate an action we must employ some multi-modal integration that allows the conversion of visual information into somatosensory information that is of use to our motor system (Meltzoff & Moore, 1995). This supramodal representation could then facilitate the conversion of a perception into an action. If we do in fact possess such an ability, there must exist neurocognitive hardware to facilitate it.

**The Mirror Neuron System and Imitation**

Certain neurons within the superior temporal sulcus of the macaque monkey fire irrespective of whether a person is executing a specific action or observing the same action being executed by another (Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). The result of this basic empirical observation was a burgeoning of research into what has been dubbed the mirror neuron system. Some ingenious research methodologies have led to the theoretical possibility that a homologous system may exist in the human brain. Functional magnetic resonance imaging (fMRI) studies in which participants were required to perform a simple hand movement found that the activation of the motor cortex increased if the participant also watches somebody else execute the same task (Iacoboni et al., 1999). Crucially, this increase in activation is specific to the motor areas that correspond with the action being observed. Moreover, it has been shown that the excitability of the motor system increases when a subject
observes an action performed by another individual (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995). This becomes increasingly interesting when we consider that transcranial magnetic stimulation has been seen to produce motor evoked potentials (MEP) both when a participant observes an action executed from their perspective and from the perspective of another (Fadiga et al., 1995). Yet, this study found that in a sample with ASD, MEPs were only facilitated when watching a task from an egocentric perspective.

Taken together these findings present a robust argument for the presence of a mirror neuron system in humans. However, the possibility of single neuron recordings that led to the discovery in macaque monkeys is not available in humans and so the precise location and functional importance of the mirror neuron system in humans remains theoretical. The mirror neuron system has been taken to mean the areas of the inferior parietal and inferior frontal cortex which respond both during action observation and execution (Rizzolatti & Craighero, 2004). More recently reservations about such an all-encompassing system subserving imitation have emerged. The primary functional role of the mirror neuron system is said to be in understanding movements in terms of goals, which may be intact in those with ASD (Southgate, Gergely, & Csibra, 2009).

Furthermore, there is evidence to suggest children with ASD are not impaired on direct mirroring of others (Hamilton, Brindley, & Frith, 2007) which suggests that the atypical imitation evident in ASD may be the result of more general factors than a general imitation impairment, which undermines the validity of a global mirror neuron deficit account of ASD (Leighton, Bird, Charman, & Heyes, 2008).

The relevance of the mirror neuron system to imitation is still potentially huge. A mirror neuron system appears to have the capacity to facilitate a supramodal representation of movement (Williams et al., 2001). Consider that when we observe another individual perform a specific action the same neurons that would be firing to allow us produce that same action automatically fire. Instead of this resulting in the automatic production of the action in the observer, areas within the prefrontal cortex inhibit the production of the movement. The result is a supramodal representation of the action that is available to the observer if they wish to imitate the behaviour. Even if they choose not to imitate the behaviour the representation is available to abstract thought and the movement may be simulated in the mind of the observer. It has also been
argued that the capacity of the mirror neuron system to embody a supramodal representation is pivotal in our ability to understand others minds (Rogers & Pennington, 1991; Williams, et al., 2001, Williams, 2008). When we observe another individual perform a certain action we may be able to retrodict aspects of their internal mental states by constructing the appropriate mental correlates of an act once it is reconstructed in our own mirror neuron system (Gallese & Goldman, 1998). A defective mirror neuron system may provide the neurocognitive explanation for a qualitatively impaired imitative ability in those with Autism, if indeed it were found to be conclusive (Meltzoff & Decety, 2003).

It has been shown that the mu rhythm over the premotor cortex is supressed during action planning which is thought to reflect down-stream modulation of motor neuron cells by the premotor cortex (Pineda, 2005). Oberman, et al. (2005) employed EEG methods to explore if there were differences between an ASD sample and controls in this suppression during action observation and execution. They found that the ASD sample, unlike controls, only experienced mu wave suppression during a task involving movement of their own hand and not in a task in which they observed another’s hand moving. A comparative fMRI study found that the increased activity in the right somatosensory cortex observed by Iacoboni and colleagues (1999) was greatly diminished in a sample of adults with high functioning Autism (Williams, Waiter, Gilchrist, Perret, Murray, & Whiten, 2006). However, there was no evidence presented to demonstrate if this particular sample were impaired on imitation tasks. If these findings do in fact represent a deficient mirror neuron system in ASD it could be argued for as the underlying neurocognitive explanation of a behavioural impairment in imitation.

**Imitation as a precursor to Theory of Mind**

The developmental importance of imitation to language, imagination and social abilities was pioneered by Piaget (1952). Meltzof & Gopnik (1993) offer a solid argument for how the practice of imitation begets the formation of a theory of mind. The logic of their argument is this: human beings are capable of social interaction because we can comprehend that others have emotions, intentions, thoughts and desires that are similar to our own. What is more, we understand that internal mental states such as these are
not simply passive reactors to the external environment but rather are formed through active interaction with it. It follows that these states vary from our own as a function of their perspective in the world. According to Meltzoff & Gopnik (1993) we come to understand others minds through simulation of their perspective. This can be fundamentally, as in the case of automatically mimicking a facial expression or a more advanced social function, by understanding their intention behind a movement by making a corollary between the movement and why we ourselves would be motivated to perform a similar action. People then begin to understand what others are thinking by observing their overt and observable behaviour. Inhibitory mechanisms are key in our ability to run these simulations offline rather than automatically producing them (Gallese, 2003). It is worth noting the simulation theory is not the only explanation of development. Theory theory is another in which infants come to understand their environment by means of creating and testing hypotheses about the world. A deficient imitation ability would have no bearing on theory theory. Perhaps explaining how such heterogeneous clinical presentations of ASD exist. Imitation deficits tend to be present before deficits in Theory of mind and as such imitation may be a precursor to Theory of Mind (Williams, et al. 2001). Investigating imitation in ASD is therefore of theoretical value.

**Empirical Evidence of a deficit in children with Autism**

*Actions-on-objects and Gestural Imitation*

A seminal study by DeMyer et al. (1972) established that children with ASD are impaired on imitation tasks in comparison to intellectually impaired children. Participants were tested on imitation of actions-on-objects and gestures. This study found those with ASD produce less imitation than controls. They were comparatively more impaired on gestural imitation of action-on-objects. However, there was a pool of 531 possible tasks participants may have been tested on. Moreover, the tasks individuals were tested on were related to their mental age and so those in the ASD sample were tested on simpler tasks. There was a large portion of within subject and between subject variance in the effect of the differences between tasks that was not accounted for. The finding that children with ASD are differentially more impaired on gestural imitation has nonetheless been widely replicated (Hammes and Langdell, 1981; Sigman & Ungerer, 1984; Ohata, 1987; Stone, Lemanck, Fishel, Fernandez &
Altemeier, 1990; Rogers, Bennetto, McEvoy & Pennington, 1996; Roeyers, Van Oost & Bothuyne, 1998). An early review of the studies on imitation in ASD concluded that the imitative deficit that was beginning to emerge in the literature was the result of atypical abilities to represent self-other correspondences (Rogers & Pennington, 1991). Rogers and Pennington (1991) postulated that this impairment was core in ASD that had a cascading effect of the developmental trajectory of language, social interaction and imaginative play.

Research has shown that children with ASD are aware of being imitated by others (Dawson & Adams, 1984) and sometimes enjoy it (Escalona, Field, Nadel, & Lundy, 2002) which preclude the possibility that an imitation deficit stems entirely from an inability to create self-other representations (Smith & Bryson, 1994). Instead, it could be argued that an imitation deficit is not a primary deficit in Autism but rather results from more basic information processing abnormalities. Smith and Bryson (1998) argued that children with Autism are least impaired on tasks that involve imitation of actions-on-objects because the presence of an object confines the combination and permutation of available movements by virtue of the fact that performing an action with a given object reduces the degrees of freedom available. Furthermore, performing an action on an object produces a change to the object which leaves at least some minimal residual trace on the environment which may aid in an imitation of an action on the object.

Symbolic and Non-Symbolic movement

Rogers, et al. (1996) manipulated the symbolic content of tasks involving facial expression, gestural movement and hand movements. They found that increasing the meaningfulness of an action aided imitative performance in an autistic sample and hindered it in a typically developing sample. Despite finding a significant main effect for group and task type (gestural or action-on-object) there was no exploration of an interaction effect and so it cannot be concluded if the manipulation of symbolic content affects these task types in different ways. Rogers, Hepburn, Stackhouse, and Wehner (2003) investigated imitation of oral-facial, gestural, and hand movements across young children with ASD, Fragile X syndrome and typical development. This study found that imitation of hand movements did not discriminate between groups. This conflicts with the findings of Rogers et al. (1996) which may indicate that factors of the tasks other
than the pure imitative ones may have differed systematically in the two studies. Interestingly Rogers et al. (2003) found imitative performance correlated significantly with the presence of ASD symptoms in the Fragile X sample.

**Emulation or Imitation?**

A study requiring children to copy a movement of an experimenter who uses their hand to touch the ear on (a) the ipsilateral side of their body or (b) the contralateral side of their body raises some interesting questions (Bekkering, Wohlschläger, & Gattis, 2000). Children in the ASD sample are significantly more likely to ignore the hand used but succeed in touching the correct ear. The authors argue that when multiple goals compete for limited resources cognitive limitations in the ASD sample lead to the goal that is most intrinsic to achieving the end-state being favoured over others that are superfluous to the completion of the task. Another explanation may be that people with ASD are capable of emulation but lack certain abilities to achieve true imitation. A number of studies have found evidence to suggest that people with Autism successfully complete tasks involving emulation but they are impaired on tasks on imitation (Aldridge, Stone, Sweeney, and Bower, 2000; Carpenter, Pennington, & Rogers, 2001).

A study investigating if children with ASD and typically developing children were able to imitate the specific form of a modelled movement that led to the end state found considerable group differences. This task require children to perform a novel action on a non-novel object, for instance move their finger along a wooden pole, in either a gentle or fast manner. Children in ASD had difficulties reproducing the form of the movement but not the action itself. Hobson and Hobson (2008) have reproduced these findings in a recent study exploring tasks in which the style of an action was intrinsic to the goal of the task. Interestingly, those with Autism were more likely to produce both the exact means of producing the end-state and the end-state itself if the style of the action was intrinsic to the goal. Typically developing children, on the other hand, were equally as likely to reproduce the style and end-state in both conditions. This may suggest that children with ASD are equally as capable of producing imitation but are simply less inclined to do so.
Social role of imitation

It is therefore necessary to consider if those with ASD are simply less motivated to copy others. Whiten and Brown (1999) devised an experiment in which children were given a box termed an ‘artifical fruit’ that had two methods of being opened. Spontaneous imitation was judged on whether or not participants copied the methods demonstrated to open the artificial fruit. Children with ASD were less likely to model the methods used by the experimenter and so the conclusion drawn was that those with ASD are less motivated to spontaneously imitate. These findings have been well replicated in more recent studies (McDuffie et al., 2007; Ingersoll, 2008). An explanation that has been offered for this is that behaving like another is of fundamental social importance and thus typically children are inclined to perform an action like another whether it is necessary or not, children with ASD only see the need to act like another when it is necessary (Ingersoll, Schreibman, & Tran, 2003). Hobson and Hobson (2007) examined the relationship between joint attention and imitation in Autism. The authors found that children with ASD spent more time than controls attending to the objects than the model; they also showed significantly less sharing looks. Crucially, the amount of sharing looks was associated with imitation of self-other orientation. There is a very real possibility that a portion of the variability in imitation performance between groups of autistic and typical children may be related to joint attentional differences.

Autistic Severity

DeMyer (1975) conducted a large study with 66 people with Autism which were characterised as having high, middle or low functioning Autism. This study found that imitation ability may indeed vary as a function of autistic severity. Charman et al. (1998) exploited an early screening tool for autistic traits to study imitation in a sub-syndromal sample. The authors of this study found evidence of an imitative deficiency in this sample. Based on these findings they argued that severity of Autism may be related to imitation ability. Indeed a strong correlation between autistic severity and imitation ability has since been found (Rogers, Hepburn, Stackhouse, & Wehner, 2003; Zachor, Ilanit, & Itzchak, 2010).
Persistence

The studies of imitation in autism discussed thus far have mostly concerned children or at eldest adolescents with ASD. In order to determine if imitation difficulties in ASD are persistent there is a need to explore these abilities into adulthood. Hobson and Lee (1999) found that imitation of style remained impaired into adulthood. Avikainen, Wohlschlager, and Hari (2003) compared imitation in a sample of adults with ASD in which participants were required to place a pen in one of two cups. There were two conditions, one in which the action was matched and the model’s right hand corresponded with the observers right hand or the mirror condition in which the models left hand corresponded with the observer’s right hand. When controls watch the action mirrored they can imitate faster than when actions are matched. Interestingly, in this study people in the Autistic sample did not profit from observing the mirror like movements. Frietag et al. (2006) has been cited as evidence that adults display subtle imitative differences from healthy controls (Vanvuchelen, Roeyers, & De Weerdt, 2010). However, the age of participants is not given in this paper they are actually referred to as adolescents and not adults. Rogers et al. (1996) studied a sample aged between eleven and twenty one years and still found significant group effects. This study did not explicitly look at the function of increasing chronological age on imitation. Adults with Autism do not automatically mimic facial expressions of others which differs from typically developing adults (McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006). A study that examined imitation in three different age brackets in Autism found the least impairment in the eldest group (Whiten & Brown, 1999). A systematic literature review also found the largest effect sizes were in the studies with the youngest samples (Williams, et al., 2004). Research investigating imitation abilities in adults is lacking and warrants further investigation.

Motor Impairments in Autism

Damasio and Maurer (1978) were the first to suggest that people with Autism may have difficulty producing movements. Empirical evidence now exists to support this claim (Miyahara et al., 1997). These researchers found 22 out of 24 people with ASD had motor impairments according to The Movement Assessment Battery for Children (MABC; Henderson, Sugden & Barnett, 1992). Systematic studies have since shown that of 101 children with ASD 79.2% have definite motor impairments on the MABC
This impairment was also significantly correlated with IQ which raises the possibility that motor impairment and mental ability are both epiphenomena explained by some more fundamental neurological explanation. A comparison of imitation between a sample with ASD and one with DCD shows that the ASD sample still present with worse imitation performance despite the fact that those with DCD are more severely impaired in their motor skills (Green et al., 2002). Yet, Mostofsky et al. (2006) have reason to believe that imitative differences can be accounted for by a praxis deficit. The relationship between basic motor skill and imitation ability remains ambiguous and more systematic investigation is required.

The Present Study

There is a definite need to investigate whether imitation deficits found to be evident in children with ASD are still evident in an adult population. In order to shed light on the effect of motor skill on imitation performance there is a need to develop a profile of motor abilities in both the control and ASD sample of the present study. It has been widely established that there is a degree of overlap between motor abilities, cognitive abilities and imitation performance. In order to ameliorate the confounding effects of motor abilities on imitation tasks the present study will investigate the profile of motor skills of a sample with ASD and a sample of typically developing adults. The control sample will be matched for age and IQ in order to control for the possible confounds of cognitive differences.

An imitation task requiring participants to copy the movements of a model in videos developed with The Clinical Kinematic Assessment Tool (C-KAT) will be used. This will produce objectively quantifiable metrics of certain kinematics of the participant’s movement. This can be compared across groups using a between subjects design. This is an important aspect of the present study given that so many of the studies in the research literature are predicated on findings from studies that have at least some subjective aspects of rating imitation performance. The present study will therefore explore the following research questions

1. Is there a difference between adults with Autism Spectrum Disorders and typically developing adults on a novel imitation task?

2. Will the people in the ASD sample be significantly more impaired on measures of motor ability
Method

Participants

Participants in this study were in two independent samples. The sample of typically developing (TD) controls comprised of 20 adults, 9 males and 11 females, who were recruited by means of an advert posted on a University of Edinburgh website for students seeking employment (SAGE). The sample of people with an Autistic Spectrum Disorder (ASD) was comprised of 10 adults, 9 males and 1 female, with a diagnosis of ASD who were recruited through the university disability office or through a drop-in service for people with ASDs. The TD sample were aged between 21 and 30 (M= 23.6, SD= 2.14) and the ASD sample were aged between 20 and 52 (M= 27.4, SD= 9.11). The difference between the two groups in age was not significant, \[ t(1, 9.499) = -1.3017, p = 0.08287 \]. Furthermore, IQ percentiles for the two groups were comparable as an independent samples \( t \)-test yielded non-significant results, \[ t(1, 10.699) = 0.6793, p = 0.3995 \]. No member of the TD sample had ever been diagnosed with any Autistic Spectrum Disorders, Dyslexia or Dyspraxia. This is reflected in a significant difference between the two groups in Autistic Severity as measured by the Autistic Spectrum Quotient, \[ t(1,6.657) = -6.5275, p=0.000 \]. All participants were remunerated a fee of £10 for their involvement.

Procedure

Ethical approval for the following procedure was granted by the Psychology Research Ethics Committee at the University of Edinburgh. All participants were given an information sheet (See Appendix A) detailing the nature of the study and were given ample opportunity to ask questions and discuss any reservations about the study. Participants who were happy to proceed demonstrated their informed consent by signing a consent form (See Appendix B). All participants recruited consented in full. All participants completed every aspect of the following procedure.

The Movement Assessment Battery for Children.

All subsections of the Movement Assessment Battery for Children, second revision (MABC-2; Henderson, Sugden & Barnett, 2007) were administered on participants. Participants were tested on tasks in age bracket three of this test battery, which were normed for children between 11 and 16 years of age. The participants in the current
study did not fall within this age bracket but the decision was taken to use this measure as it is the gold standard tool for assessing people for motor impairments. The assumption was made that participant’s performance on tasks designed for administering at an earlier age would still be highly predictive of current abilities. There are three subscales to this test; manual dexterity, aiming and catching, and balance. Measures generated from this battery were overall percentile rank on the MABC-2 and standardised scores on each of the subtests (For more details see Appendix C).

C-KAT

Participants were then tested on a battery of movement tasks from the Clinical Kinematic Assessment Tool (C-KAT; Culmer, Levesley, Mon-Williams, Williams, 2009). C-KAT is a computer program that was presented to participants on a Toshiba Model Tectra M7 tablet laptop. The screen of the laptop was rotated and folded back to provide a horizontal plane. Participants were given a stylus and asked to hold it as if holding a normal pen. This facilitated interaction between the stylus and the screen of the tablet computer that was akin to that of pen and paper. The CKAT program recorded a number of kinematic variables that defined how a participant moved the stylus across the screen of the tablet. A number of tasks were presented to participants that required them to (a) follow a moving dot around the screen with the stylus, (b) move the stylus from one dot to the location of a new dot that appeared at the points of a pentagram shape and (c) trace inside the lines of some abstract shapes using the stylus. These tasks generated a metric of path accuracy for tasks a and c and metrics of reaction time, deceleration time, movement time, peak speed, and path length for task b. See Appendix D for more details.

Imitation task

An experiment was designed to test imitation abilities using the C-KAT computer program. Participants had a Toshiba tablet computer placed in front of them and a second laptop was placed on the table in front of the tablet computer. Video clips were presented on this laptop screen depicting some shapes being drawn on a tablet identical to the one they had in front of them. Participants were asked to watch each video clip and when the clip finished playing, imitate to the best of their ability the shape that was drawn, paying attention to the size and speed at which it was drawn. There were two
experimental conditions; one in which a model drew the shapes (Model) and another in which a dot moved around the screen to produce the shapes (Dot).

The Video Clips

A set of video clips were recorded from an allocentric perspective, meaning from the viewpoint of someone observing the stimulus directly in front of them. In the Model condition a person seated in front of the tablet computer drew three shapes (circle, square, triangle) at three speeds (slow, medium, fast) and in three sizes (small, medium, large). So in total there were 27 trials (3 shapes X 3 speeds X 3 sizes). A screenshot from one of these videos can be seen in Figure 1. While these videos were being recorded the C-KAT program also recorded the kinematics of the models movements on the screen.

![Figure 1. A screenshot from one of the videos used in the Model condition](image)

In the Dot condition the model was sitting in front of the tablet exactly like in the Model condition, but crucially the model only watched the screen in these videos. None of the model’s movements in this video were required to be imitated. Instead, a module within C-KAT used the kinematic data of the shapes drawn whilst recording the Model condition to replay the same 27 trials being drawn. The trials this time consisted of a black dot that moved around the screen to create the shape. The model was included in these video clips to control for visual saliency between the two conditions and to ensure that joint attentional differences didn’t confound any findings. These clips were recorded at a slightly more obtuse angle than the model condition to make it easier to see the screen of the tablet, a screenshot from one of these video clips can be seen in Figure 2.
Figure 2. A Screenshot from one of the videos used in the Dot condition

The tablet in front of the participants had a blank white screen with one black dot on it. This dot was the start/end point and was the same in every trial. This corresponded with a dot on the screen of the tablet in the video clips. The order of all 27 trials was pseudo-randomised in each condition; the randomisation was different for the two conditions. The order of presentation of Dot and Model conditions were counterbalanced with each successive participant receiving an alternating condition first. The video clips recorded were presented using Microsoft Office Powerpoint (Microsoft, 2011). Participants were instructed that they could request to be shown a video a second time if they did not see it. Each clip was shown and after the clip finished a screen appeared that read ‘Now you do it’ and only then were participants required to copy the shape seen.

Once participants placed the stylus on the start/end dot on the screen the trial began and C-KAT began recording their movement. When the stylus entered the area covered by this dot again the trial ended. The C-KAT program generated a measure of path length (measured in pixels) and speed (measured in seconds) for each participant for each trial in each condition. Mean speed could then be determined from these by dividing path length by time. For more information see Appendix D.

WASI

The vocabulary and matrix reasoning subtests of the Wechsler Abbreviated Scale of Intelligence (WASI; Weschler, 1999) was administered for each participant. An IQ percentile rank was tabulated for each participant based on their performance on these subscales.
The AQ

Each participant completed the Autistic Spectrum Quotient (AQ; Baron-Cohen, Wheelright, Skinner, Martin, & Clubley, 2001) for this study. Participants completed a computerised version of this scale whereby the scores were tabulated automatically.

Statistical Analysis

Statistical analysis was conducted on the data generated by this study using the ‘R’ statistical package (R core development team, 2010).
Results

Motor abilities

Participant’s scores on the Movement Assessment Battery for Children, second revision (MABC-2) were compared to see if there was an overall group difference between the TD and ASD groups on motor abilities. A majority of the variables relating to the MABC-2 violated the assumptions of normality. Thus, the decision was made to conduct non-parametric analyses on this section. A one-tailed Mann-Whitney U test was conducted to evaluate the hypothesis that people in the ASD sample would score significantly lower on the MABC-2 than their TD counterparts. The results were in the expected direction and significant, $z = -2.851, p = 0.004$. A summary of the group differences can be seen in Table 1.

<table>
<thead>
<tr>
<th>Ranked Means</th>
<th>ASD</th>
<th>TD</th>
<th>$z$</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MABC Percentile</td>
<td>9.1</td>
<td>18.7</td>
<td>-2.851</td>
<td>0.004*</td>
</tr>
<tr>
<td>Dexterity</td>
<td>13.1</td>
<td>16.7</td>
<td>-1.070</td>
<td>0.307</td>
</tr>
<tr>
<td>Aiming</td>
<td>10.1</td>
<td>18.2</td>
<td>-2.388</td>
<td>0.017*</td>
</tr>
<tr>
<td>Balance</td>
<td>11.6</td>
<td>17.45</td>
<td>-1.811</td>
<td>0.091</td>
</tr>
</tbody>
</table>

Note: * = Significant at $p<0.05$
     = Significant at $p<0.1$

Further examination of the subscales of the MABC-2 yield some interesting results. The Autistic sample does not differ significantly from the TD sample in terms of their scores on the fine motor dexterity subscale, $z = -1.070, p = 0.307$. The ASD group were significantly more impaired on the aiming and catching subscale of the MABC-2, $z = -2.388, p = 0.017$. While the difference between the two groups on the balance subscale was not statistically significant it was trending towards significance, $z = -1.811, p = 0.091$.

The non-normal distributions of scores on some of the subscales were due to a large portion of participants performing at ceiling on certain aspects of the test battery, for example 10 people in the TD sample performed at ceiling in the balance subtest. This was possibly due to the fact that it had been normed for a younger sample than that of the present study. The distribution of scores was compressed and meant statistical
power to determine a difference was lowered. Considering the combination of these ceiling effects and the limited power in the present study it was decided to explore the relationship between MABC-2 scores and autistic severity, as measured by the AQ. This examines Autism as a continuous variable rather than a categorical one which is justified given the spectral nature of the condition. This is further justified given that there was no overlap in AQ scores between the two groups. Spearman’s rho correlations validated the relationship between Autistic severity and MABC-2 percentile ranks, \( r (30) = -0.5, p = 0.009 \). Furthermore, there was a high correlation between AQ and balance, which was highly significant, \( r (30) = -0.707, p = .000 \). Figure 3 depicts this relationship graphically

![Figure 3](image)

**Figure 3.** The Relationship between AQ scores and scores on the balance subscale of the MABC-2 with fitted regression line.

**C-KAT**

The movement battery from the C-KAT program was used to further explore fine motor dexterity abilities like those explored by the dexterity sub-section of the MABC-2. Each of the variables generated from this task met the assumptions for parametric analysis. A number of Independent sample \( t \)-tests were used to determine if there was a significant difference between groups on any of the measures generated by the C-KAT computer program. There were no significant group differences generated by any of the measures on the CKAT program (the results of these tests are summarised in Table 2). This
further validates the findings that there was no reliable difference between the ASD group and the TD group in terms of fine motor dexterity.

<table>
<thead>
<tr>
<th>Variable investigated</th>
<th>TD Mean</th>
<th>ASD Mean</th>
<th>df</th>
<th>t</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Time</td>
<td>0.356</td>
<td>0.324</td>
<td>12.18</td>
<td>1.39</td>
<td>0.191</td>
</tr>
<tr>
<td>Movement Time</td>
<td>0.467</td>
<td>0.55</td>
<td>8.663</td>
<td>-2.05</td>
<td>0.071</td>
</tr>
<tr>
<td>Deceleration Time</td>
<td>0.266</td>
<td>0.326</td>
<td>9.422</td>
<td>-1.98</td>
<td>0.078</td>
</tr>
<tr>
<td>Peak Speed</td>
<td>388.90</td>
<td>342.08</td>
<td>12.39</td>
<td>1.51</td>
<td>0.156</td>
</tr>
<tr>
<td>Path Length</td>
<td>115.24</td>
<td>116.50</td>
<td>11.37</td>
<td>-1.70</td>
<td>0.116</td>
</tr>
<tr>
<td>Path Accuracy (Tracking)</td>
<td>1.11</td>
<td>1.53</td>
<td>19.2</td>
<td>-1.20</td>
<td>0.244</td>
</tr>
<tr>
<td>Path Accuracy (Tracing)</td>
<td>0.581</td>
<td>0.735</td>
<td>22.63</td>
<td>-1.32</td>
<td>0.202</td>
</tr>
</tbody>
</table>

Overall group differences in motor abilities appear to be stemming from more gross body movements such as those explored by the balance and catching subscales of the MABC-2. Considering the absence of group differences in fine motor dexterity, more specifically in tasks that require movement of a stylus on the tablet screen mean that assessing imitation of movements such as those in the C-KAT can demonstrate imitation abilities independent of any motor differences between the two samples in the present study.

**Imitation task**

The imitation task generated values for path length, time and speed for each participant in each of the 54 trials (27 Dot and 27 Model). Given, that C-KAT recorded the same kinematic variables while the model drew the shape in the videos, we compared the kinematic variables of the model and each participant on each trial. It was then determined if the relationship between any of these variables differed systematically as a function of group. Individual and model kinematics were compared in two ways; first the extent to which the shape drawn by a participant correlated to the shape drawn by the model for a given variable was determined. It was then determined if these correlations differed significantly between groups. Second, accuracy and precision of shape drawn were calculated and it was determined if either of these vary as a function of group.
Correlation of Participant and model kinematics

The extent to which each participant’s measure of path length, time, and speed for each shape correlated with the path length, time and speed of each corresponding shape produced by the model was explored using Spearman’s rho correlations. The correlation coefficient for each kinematic variable for each participant can be seen in Appendix E. These coefficients allowed exploration of the relationship between condition and group membership. For explanatory purposes, figure 2 depicts the correlation between one member of the typically developing sample and one member from the ASD sample in (a) the Dot condition and (b) the Model condition. This graph shows that the correlation for both individuals appears to follow the same slope, with the participant from the ASD sample showing a lower intercept. There also appears to be more overlap between the two groups on the Model condition. However, this is only the results of one participant from each sample on one of the kinematic variables. The mean correlation coefficients for each group in each condition can be seen in Figure 5. In order to investigate these relationships more thoroughly and determine significant differences a Multiple Analysis of Variance (MANOVA) was run.

![Graph](image)

*Figure 4. Relationship of path length of one typically developing and one autistic participant in the (a) dot and (b) imitation conditions*

*Fisher’s r-z transformation*

Before any test statistics could be run the correlation coefficients were transformed using Fisher’s r-z transformation. This was done to stabilise the variance of the data, as
without such a transformation the variance of $r$ decreases the closer it gets to 1. Data displayed in Figure 5 is back transformed to correlation coefficients.

![Figure 5](image_url)

**Figure 5.** Summary of mean Spearman’s correlation coefficients on each kinematic variable for both groups in both conditions with error bars depicting the standard deviation.

This data met all of the assumptions for multivariate normality. A 2 X 2 within subjects multivariate analysis of variance (ANOVA) was conducted to investigate whether group membership or experimental condition significantly affected correlations between individual’s measures of path length, time or speed with those of the model. A MANOVA was favoured over multiple univariate homologues because given the related nature of the dependent variables multiple ANOVAs would have inflated the Type I error rate. This MANOVA found that there was no significant main effect of group for path length, $F(1,54)=0.008$, $p = 0.927$, time, $F(1,54)= 1.8$, $p = 0.184$, or for speed, $F(1,54)= 0.015$, $p = 0.903$. There was a trend towards significance for the main effect of condition on time, $F(1,54)=2.934$, $p = 0.092$. Investigations of means indicate that the time taken to draw shapes by participants was closer to the time taken by the model in the video in the model condition than in the dot condition, which did not vary as a function of group. In any case the finding is not significant. There were no significant interaction effects at play here. This analysis therefore indicated that whether or not participants were in the ASD or TD group or performing in the Dot or Model condition
did not significantly effect the correlation of their path length, time or speed with those of the model.

**Constant Error and Variable Error**

The measure generated by the model for path length, time and speed in each trial was deducted from the equivalent score of each participant. This generated a measure of overall deviance from the measure generated by the model. Individual’s mean overall deviance from the model was calculated for all 27 trials of each condition for path length, time and speed. This measure will be referred to as constant error and it represents how accurate the movement of participants was. The mean constant error and standard deviation of constant error were determined for each group. The standard deviation of participant’s overall deviance in the Dot condition was also calculated. This will be referred to henceforth as variable error and it represents how precise participants movement was. The mean variable error and standard deviation of variable were determined for each group. Constant and variable errors for each group in each condition can be seen in Table 3.

Table 3.  
Means (standard deviations) of constant and variable error scores across condition and group

<table>
<thead>
<tr>
<th></th>
<th>Constant Error</th>
<th>Variable Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dot</td>
<td>Imitation</td>
</tr>
<tr>
<td>Path</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>-1.319 (28.248)</td>
<td>0.237 (25.769)</td>
</tr>
<tr>
<td>ASD</td>
<td>-3.825 (41.004)</td>
<td>-1.297 (29.501)</td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0.025 (0.15)</td>
<td>0.035 (0.139)</td>
</tr>
<tr>
<td>ASD</td>
<td>0.179 (0.413)</td>
<td>0.13 (0.268)</td>
</tr>
<tr>
<td>Speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>-15.778 (50.528)</td>
<td>-4.567 (23.5)</td>
</tr>
<tr>
<td>ASD</td>
<td>-20.485 (40.347)</td>
<td>-16.59 (29.094)</td>
</tr>
</tbody>
</table>

This data met all of the assumptions for multivariate normality. A 2 X 2 within subjects MANOVA was conducted to investigate if group membership or condition significantly affected the constant or variable error for path length, time and speed produced by participants. Once again no significant main effects for group emerged. The main effect of group did approach significance for speed, F(1,53)= 3.584, p = 0.064. Indeed there was no significant effect of experimental condition, nor was there any significant interaction between group and condition.

Based on the above results there is no evidence that the ASD group performed significantly worse on either condition of the imitation task. Given that we found no
evidence that the two groups differed on the aspects of motor skills relevant to this task it can be argued that imitation abilities in both groups are compared in an equal domain. A discussion of these results follows.
Discussion

The results of the present study indicate that there was no reliable difference between the Autistic Spectrum Disorder and typically developing samples on the imitation task they were tested on. This is of interest to the primary research question of whether or not imitative deficits in ASD are pervasive through into adulthood and supports the conclusion that they are not. Given that these two samples did not differ systematically in the domain of motor skills employed to perform this task, in age, or in IQ all add to the rigour of this finding.

The finding that an adult sample of people with ASD do not appear to be deficient in imitation is supported by studies that have found that the largest effect sizes in comparative studies of imitation appear to be in the youngest samples (Whiten & Brown, 1999; Williams et al., 2004). However, the above finding is not supported by studies that found adults to be impaired on imitation (McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006; Beall, Moody, McIntosh, Hepburn, & Reed, 2008; Leighton et al., 2008) or indeed those who purport imitation is a core deficit in ASD (Rogers & Pennington, 1991; Smith & Bryson, 1994, Williams et al., 2001; Williams et al., 2004, Williams, 2008; Sevlever & Gillis, 2010). Whether or not this disparity is as a result of increasing chronological age on imitation abilities in ASD or an artefact of the subtle differences in the nature of the imitation task in the present study and those used in the studies that found impairments is not immediately obvious.

One such difference in task type is whether or not the imitation under exploration is elicited or spontaneous. The task employed to investigate imitation in the present study is intrinsically elicited. Not only were participants asked to imitate the action of the model but they were told explicitly which aspects of the movement to imitate. Suggesting that the lack of group differences may have been accounted for by the fact that in this task participants performed the action presented and its component parts and in other studies some aspects of the action was not reproduced because participants were not explicitly asked to do so. If this is the case it supplements the hypothesis that those with ASD are as capable of imitating the action of another but are simply less inclined to do so. This theory is supported by the findings that people with ASD are less impaired on elicited tasks rather than spontaneous imitation (DeMyer, et al., 1972; Whiten & Brown, 1991; McDuffie et al., 2007; Ingersoll, 2008).
Participants with ASD may also have been less impaired than literature would suggest they should have been because the task involved imitating an action-on-object, which is known to be less impaired than gestural aspects of imitation (Hammes and Langdell, 1981; Sigman & Ungerer, 1984; Ohata, 1987; Stone, Lemanck, Fishel, Fernandez & Alteneier, 1990; Rogers, Bennetto, McEvoy & Pennington, 1996; Roeyers, Van Oost & Bothuyne, 1998). If indeed this is why imitative performance is comparable between the two groups it is unclear whether an imitation deficit would have emerged in a task investigating gestural imitation in the present sample. It may suggest that the current study is in line with the finding that tasks involving actions are performed by some system that is less impaired in people with ASD than the neurocognitive hardwire responsible for gestural imitation. It may be that the difference is merely the reflection of reduced degrees of freedom and object affordances as discussed by Smith & Bryson (1994;1998;2007).

Furthermore the actions participants were required to imitate in the present study held symbolic meaning. That is to say the model drew basic geometric shapes that hold semantic meaning. It is probable that experience of these shapes may have aided in the reproduction of a models movement. This may be because upon observing a given shape a participant could use linguistic internal instructions to guide them to draw the given shape. The resultant movement would thus be influenced by factors other than the movement of the model. The same can be said for size and speed. This may be why verbal intelligence is seen to be associated with imitative performance (Rogers et al., 2003) and explain activations of Broca’s area in imitation tasks (Williams et al., 2006).

In addition, the ASD sample was a relatively high functioning group who were for the most part attending university. The finding that imitation ability may be associated with autistic severity (DeMyer et al., 1975; Rogers, Hepburn, Stackhouse, & Wehner, 2003; Zachor et al., 2010) may explain why no difference was evident between the groups in the present study.

Considering the imitation task in the present study elicits a response, involves action-on-objects, and is symbolically meaningful which are all known to produce smaller effects than their antitheses would suggest that if there is a difference between the two groups the effect size would be relatively small. The small sample sizes in the present
study may not have produced sufficient statistical power to determine a difference. Furthermore, the C-KAT program may not have been sensitive to these differences. One glaring caveat of the present study is the fact that no analysis was run on shape. Path length and measures of movement time were all that were examined. While these are related to the shape drawn there a possibility that participants were producing an entirely wrong shape which wasn’t producing large errors on the measures investigated. Insofar as a person may have drawn a circle instead of a square but the path length and speed at which it was drawn may have been comparable to the square drawn by the model. The C-KAT program was not sensitive to this. Additionally, the C-KAT program did not register every trial because the program is sensitive to artefacts such as waiting too long to begin a trial, lifting and re-placing the stylus and not registering the start of a trial. It is therefore not unreasonable to argue that the cases in which data is missing may represent significantly worse performance. This was not accounted for by the statistical analysis. The C-KAT program is not a commercially produced piece of software and further recording artefacts may be present in the data. For example, a lack of sensitivity of the software to placing the stylus on the end dot may mean longer times are recorded for tasks that the actual time taken to completely draw the shape. This may introduce some noise in the data that are masking the true distribution.

Despite the aforementioned caveats another MSc project that was conducted in parallel to this one found an association between autistic severity and imitation ability in children with ASD (Hannah Stewart, personal communication). Moreover, this study found that increased chronological age improved imitation ability, at least for the control sample. The sample used in the above study was also larger meaning the difference in findings may be as a result of increased statistical power. The sample in the above study were likely to be lower functioning or at least more heterogeneous in terms of autistic severity than the sample in the present study. Unfortunately gross motor abilities were not controlled for in this study and so it is not clear if basic motor skills were more impaired than in the sample of children than in the present study. It does indicate that the C-KAT imitation task is sufficiently sensitive to discriminate between groups, at least when the effect size and sample size are adequate.

There are a number of strengths that make the present study somewhat robust. For instance, the ASD sample was relatively homogenous considering they were all high
functioning individuals. A thorough profile of motor abilities was determined for both samples in the study allowing consideration of motor abilities in imitation. The age and IQ of the samples were matched. The variables that were compared to determine imitation performance were computer generated which first of all eliminated the possibility of human error but more pertinently are objectively quantifiable. This removes the subject aspect that is evident in so many studies of imitation. Finally, a condition in which the imitation performance could be compared with the simply object movement meant it could be determined if either sample was better at reproducing

Measuring the kinematics of a participant precisely using the C-KAT provided the opportunity to determine if the movement produced by participants fulfilled the criteria for true imitation as determined by Sevlevery and Gillis (2010) or simply emulation. This is done by comparing the speed at which shapes were produced. In fact, the variable error of speed was the dependent variable that was closest to being significantly different across groups. This may theoretically represent a difference in producing the style of an action that Hobson and Lee (1999) found to be impaired in those with ASD, including an adult sample. In any case, the effect size was not great enough to produce a significant difference in the present study.

Another finding of interest from the present study is that the ASD sample differed significantly from the control sample in terms of motor ability as assessed by the MABC-2. While there was no significant difference in the domain explored in the imitation task used in this study, differences in gross whole body type movements may be confounding imitation tasks conducted in the past. For instance, tasks involving large arm movements and whole body movement have been found to be more impaired than fine motor dexterity copying of distal hand movements (Williams & Rogers, 2006). This may represent difference in the motor skills in more gross body movements.

The present study has some theoretical ramifications. Namely, that it does extend support to the view that those with impairment of imitation in ASD is absolute. It demonstrates the need to control for movement abilities in studies of imitation. It is important the participants are compared on imitation tasks that explore equivalent levels of motor skill in order not to confound any results. The importance of situating findings about imitation in relation to the tasks used in a study needs to be adopted more to allow generalisation across tasks. Future research should therefore, strive to maintain
more constants between studies so that specific findings can be attributed to the variable manipulated.

In conclusion, high functioning adults with Autism Spectrum Disorders are not impaired on the aspects of an imitation task explored in this study. Whether or not this finding is due to controlling for motor impairments in the domain investigated or due to an amelioration of an imitation deficit associated with increased chronological age remains somewhat unclear. Widely varying imitation tasks, control samples, autistic severity, factors controlled for and movement impairments make it difficult to generalise between studies of imitation in ASD. Given that a study employing the exact same protocol for assessing imitation in children with ASD has found significant group differences is suggestive that imitation deficits, at least in fine motor, object-on-action, symbolically meaningful actions are alleviated with increased chronological age. However, further research needs to determine if this is true of other forms of imitation or if the findings are due to an insensitivity of the imitation task used. In so doing future research in this field should account for the differing motor abilities of the samples used and specific research questions should be addressed with parallel studies in which only one aspect is manipulated such as that done in the present study in order to draw parallels between findings.
References


Appendices

APPENDIX A: Information Sheet Given to Participants

Information Sheet

Study Title: An investigation into imitation abilities in people with Autism Spectrum Disorders and age-matched controls

Dear Volunteer,

You are being asked to participate in a study investigating imitation ability in adults with Autistic Spectrum Disorders. You are being asked to participate because you are an adult with an Autistic Spectrum Disorder or because you fit the criteria to be in a comparison group of age matched controls. Below is the information you will need to make an informed decision about participation.

Participation is Voluntary

Taking part is entirely voluntary. If you do decide to take part, you are free to withdraw at any time. You do not have to provide a reason for withdrawing. Even if you complete the study, but decide that you do not want your data to be used, you can ask to have your data removed at a later date.

What you will have to do if you take part?

You will be asked to take an IQ test and complete two tests that measure your movement and movement-copying abilities. While you are performing one of these sets of tasks we will ask if we can make a video recording of you. If you do not want this video to be taken you can still participate and we will not record you. Testing will be done in one session of one hour and thirty minutes or in two sessions of 40 minutes each.

Will my scores be kept confidential?

Your scores on the IQ test and movement tasks will not contain your name or any identifiable information, but will be recorded using an anonymous study code. Only the researchers will be able to link you to your study code. If you consent to have your video recorded, you may be personally identifiable from this recording, but only the researchers will have access to the
recording, and it will be destroyed once the necessary scores have been taken from the video. All of the scores will be kept on password protected computers.

**What will the results of this research be used for?**
The results of this study will be used as part of an MSc and a PhD thesis in Psychology. The results may also be written up for publication in a journal and may be presented at academic conferences.

For more information do not hesitate to contact the postgraduate students in Edinburgh University Psychology department who are conducting this research:

Lorcan Kenny (xxxxxxx@sms.ed.ac.uk) or Louisa Miller (xxxxxxxx@sms.ed.ac.uk)

This study has been approved by the Edinburgh University Psychology Research Ethics Committee.
Consent Form

Please place a tick (v) in each of these boxes if you consent to what is being asked

- I have read the information sheet attached
- I have had a chance to ask questions about this study
- I agree to take part in this study
- I agree to be recorded during one of the tasks
- I understand that I may withdraw from this study at any time

Name (Block Capitals): __________________

Date: __________

Signature: __________________
APPENDIX C: Details of the MABC-2

Manual dexterity is assessed by timing participants as they turn pegs over and replace them into the same slots on a board. Participants are timed and the time taken to turn over all 12 pegs is recorded on two trials for each hand. The fastest time for each hand is used in determining scores. The time it takes participants to secure three lengths of plastic together using nuts and bolts and by measuring the accuracy of a tracing task is recorded on two trials, the fastest time is used to derive scores. Finally, participants are required to trace within the lines of two abstract shapes, the amount of errors are measured and used to determine participants score on this subtest.

Aiming and catching is assessed by getting participants to stand 1.5 metres away from a wall. They are instructed to throw the ball against the wall 10 times and catch it cleanly in one hand. The amount of successful clean catches out of ten is used to determine participant’s scores. This is done for both hands. Participants are also required to throw a ball at a wall target from behind a line that is 2.5 metres from the wall. The bottom of this target is placed in line with the top of participants head so the relative height of the target is the same for everyone. The amount of times the target is successful hit is measured and used to determine the score.

Balance is assessed by recording how long participants can balance on a thin block with both feet in a straight line positioned toe-to-heel. This is done for up to a maximum of 30 seconds. The length successfully balanced is used to determine static balance. Dynamic balance is determined by asking participants to hop between five mats in a zigzag layout. The number of successful hops made on each leg is recorded and used to determine a score for dynamic balance.

Scores for all three subtests are tabulated and compared to normed data in order to determine a subtest score for each of the subtest and a percentile rank for overall MABC-2 performance.
APPENDIX D: C-KAT description and photo!

**Tracking** This task began with a red dot on the screen. As soon as a participant placed the tip of the stylus on this dot it began moving. The dot moved around the screen in the shape of an infinity sign (∞). Participant’s task was to move the stylus around the screen with the dot and keep the tip of the stylus on the dot as best they could. There were three different speeds at which the dot moved. These different speeds were not partitioned into discrete trials. Participants began at the slowest speed which flowed into each of the progressively faster conditions. Each participant completed two trials of this task. In the first trial the screen was completely blank except the moving dot on the screen. In the second trial there was a line shape on the screen along which the dot moved. The CKAT program generated a measure of overall path accuracy across all three speeds in both conditions.

**Pentagram Task** In this task participants placed the stylus on a start point on the computer screen. Participant’s task in this test was to move the stylus to the location of a new dot that appeared at another point on the screen. As soon as the stylus touched the location of the dot it disappeared and a new dot appeared on another part of the screen. This pattern continued until a total of 22 dots had been presented. The dots appeared at the extreme points of a pentagram in the same order. The overall outline of the pentagram was not presented on the screen. This task develops a number of variables, namely: reaction time, movement time, peak speed, deceleration time, and path length for each participant.

**Tracing task** Participants were presented with two abstract shapes and asked to trace within the lines of these shapes. Once a participant touched the start button with the stylus a box appeared over the first section of the abstract shape. This box moved along the shape to control the speed at which participants completed the task. The movements of the box was not continuous it moved in a number of movements. This task generated a metric of path accuracy for shape A and for shape B which were collated to generate one measure of path accuracy.
APPENDIX E: Correlations between model and participants on kinematic variables in CKAT

Table 4

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<th>Participant</th>
<th>Path Length</th>
<th>Time</th>
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