Goal-Directed and Goal-Less Imitation in Autism Spectrum Disorder

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Abstract To investigate how people with Autism are affected by the presence of goals during imitation, we conducted a study to measure movement kinematics and eye movements during the imitation of goal-directed and goal-less hand movements. Our results showed that a control group imitated changes in movement kinematics and increased the level that they tracked the hand with their eyes, in the goal-less compared to goal-direction condition. In contrast, the ASD group exhibited more goal-directed eye movements, and failed to modulate the observed movement kinematics successfully in either condition. These results increase the evidence for impaired goal-less imitation in ASD, and suggest that there is a reliance on goal-directed strategies for imitation in ASD, even in the absence of visual goals.

Keywords Imitation · Autism spectrum disorder · Motor control · Eye movements · Sensorimotor integration

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Voluntary imitation is the ability to purposefully copy the behaviour of another agent. It is essential for learning new behaviours and transferring cultural knowledge between individuals (Whiten et al. 2009). In this respect, imitation plays a role in social relationships, enhancing interpersonal bonding by signaling and generating feelings such as affiliation (Chartrand and Bargh 1999; Lakin and Chartrand 2003; Van Baren et al. 2009). It is therefore not surprising that imitation has been explored in people with autism spectrum disorder (ASD) who have impairments in social understanding and communication. Numerous studies have documented that individuals with ASD have difficulties with imitation, suggesting that there may be a link between imitation and social ability (Rogers et al. 2003; Williams et al. 2001; Gowen et al. 2008; Leighton et al. 2008; Iacoboni and Dapretto 2006; Vanvuchelen et al. 2007; Williams et al. 2004). Of particular relevance for the current work is the observation that imitation directed towards goals appears relatively intact compared to goal-less imitation or imitation of meaningless actions (Hamilton et al. 2007; Hobson and Lee 1999; Hobson and Hobson 2008; Rogers et al. 1996; Stone et al. 1997; Williams et al. 2004). In the current study, we explore this apparent dichotomy further, by measuring eye and hand movements during goal-directed and goal-less imitation.

It has been suggested that there are two routes for imitation; a semantic route for meaningful, or goal-directed actions, and a direct route, for actions which are novel, or do not have a goal (Rumiati and Tessari 2002). The goal-directed theory of imitation (GOADI, Bekkering et al. 2000; Wohlschlagel et al. 2003) suggests that in order to imitate, the observer creates a cognitive hierarchy of goals for the action during observation, and then performs an imitative action based on those goals. This implies that the end-point of an action would be preferentially imitated (i.e. the final

goal of the action), whereas the way it is reached may not be imitated as well (i.e. the means or style of the action). In goal-less imitation, the movement style would move up the hierarchy to become a goal, as no other information about the movement is available. This pattern was shown in a previous study investigating goal-directed and goal-less imitation in neurotypical participants (Wild et al. 2010); when visual goals were absent, changes in movement kinematics were imitated more successfully. It was concluded that better imitation of movement changes in the absence of goals is a result of visuomotor mapping of the action in the direct route, and because in the absence of a goal, the style of the movement itself becomes the main focus.

Based on the dual route model, the fact that people with ASD have impaired goal-less imitation but relatively intact goal-directed imitation suggests that the semantic route for imitation is functioning, and that it is the direct visuomotor route which is impaired. In accord with this, Hamilton (2008) proposed a model suggesting that individuals with ASD are able to process goal directed actions via an emulation and planning route, but that the pathway for mimicry of low level kinematic features is compromised. To test the hypothesis that individuals with ASD have impairments of the direct visuomotor route, an ASD and a matched control group took part in a modified version of a paradigm used in a study by Wild et al. (2010). Importantly, this is the first study to our knowledge that quantitatively measures both movement kinematics and eye movements during imitation in people with ASD. Participants performed an imitation task in which the speed, amplitude or elevation of an observed hand movement differed, and imitation performance was compared during goal-directed and goal-less actions. Goals consisted of simple visual targets as opposed to higher level, meaningful goals. It was predicted that the control group would imitate changes in observed movement kinematics more accurately in the goal-less compared to goal-directed condition, due to increased visuo-motor mapping occurring along the direct route. However, no such improvement would be observed in the ASD group, as a result of an impaired direct pathway for imitation.

Eye movements were also recorded during the task, to ascertain if altered eye movements or fixation patterns, might have an influence on imitation ability. It was predicted that the control group would place importance on targets in the goal condition, and would therefore spend more time looking at the target areas (fixation), and less time tracking the moving hand (smooth pursuit eye movement). In the goal-less condition, it was predicted that an increased interest in the hand would produce an increase in smooth pursuit eye movements tracking the hand movement. Predictions for the ASD group were different. If more importance is placed on goals, and goal-less imitation is impaired, one would expect

more time to be spent fixating target areas, than would be spent pursuing the movement between the targets in both goal-directed and goal-less conditions. This pattern would also be predicted from previous research showing that people with ASD have difficulty with disengaging from targets in observed scenes (Landry and Bryson 2004) and exhibit altered eye movements (Glazebrook et al. 2009; Goldberg et al. 2002; Karatekin 2007). Additionally, no increase in smooth pursuit movements in the goal-less condition were predicted for the ASD group, based on findings that people with ASD exhibit less interest in human activity (Celani 2002), and have problems with processing biological motion (Freitag et al. 2008).

Method

Participants

Sixteen ASD participants (5 female) volunteered for this experiment, along with sixteen age, sex and IQ matched healthy controls. ASD participants were recruited through the National Autistic Society (NAS) and the Autistic Society Greater Manchester Areas (ASGMA) websites, and other volunteer advertisements. ASD participants had been given a diagnosis by outside clinical assessment (DSM IV criteria, American Psychiatric Association, 1994 or ICD-10, WHO, 1994) of either high functioning autism ($n = 2$) or Aspergers syndrome ($n = 14$). Diagnosis was confirmed using module 4 of the Autism Diagnostic Observation Schedule (ADOS). Six of the sixteen ASD participants reported co-morbidity of depression, but no other visual or neurological disorders were present in the group. Mean age ($\pm$ SD) of the ASD and control participants was 30.63 ± 7.9 and 29.31 ± 8.38 respectively. Mean IQ ($\pm$ SD) measured using the Wechsler Abbreviated Scale of Intelligence (WASI) was 120 ± 12.4 for the ASD group and 119.8 ± 11 for the control group. Age and IQ did not differ significantly between the two groups (age $t(15) = 1.085$, $p = 0.295$, IQ $t(15) = 0.046$, $p = 0.964$). All control participants, and 13 ASD participants were right handed, and all had normal or corrected-to-normal vision, and 60 s arc stereo acuity measured using the TNO test. Participants gave written informed consent and the study was approved by both the University of Manchester, and the NHS research ethics committees.

Apparatus

Participants were seated at a wooden table in the centre of the laboratory, facing the display screen ($1,000 \times 750$ mm), which was positioned 1,200 mm in front of the participant seat. Polhemus Liberty motion tracking equipment and Motion Monitor software (Innovative Sports Training) were

used to collect movement data from participants. A motion sensor was attached to the distal phalange of the index finger of the dominant hand. Movement was sampled at 120 Hz, and was tracked in X, Y and Z coordinates. The participant's view of their dominant hand was occluded during the experiment using a box, to ensure that performance would not be modulated by visual feedback; their non-dominant hand was positioned on a keyboard to allow a button press to be made to initiate the task.

Stimuli

Visual stimuli were presented using Matlab (Mathworks Inc.), back-projected onto the display screen at life-size. Stimuli were short video clips showing a human hand, termed the “demonstrator hand”, visible to just beyond the wrist, moving in a series of short sequences across a black table surface (Fig. 1). In half of the video clips, the hand pointed to visual targets, consisting of four yellow circular stickers (diameter 19 mm), positioned 150 mm apart (centre to centre, or 100 mm apart in short clips), in a horizontal line, parallel with the bottom edge of the screen. These are termed target clips (Fig. 1a). At the start of each

clip, the hand was positioned with the index finger placed on one of the four targets. During the clip, the hand moved from the start position to another target, and then again to a third target. The other half of video clips were identical to the target clips, except they did not contain visual targets and are termed no-target clips (Fig. 1b). In order to guide the demonstrator during filming, small marks drawn onto the table surface in the same places as target locations were used, that were not visible on camera. The kinematics of the demonstrator's hand movements were also measured using the Polhemus motion tracker during recording of the video clips, to allow a direct comparison between the movement modulation which participants observed and produced. The hand in the video clips was recorded in four different conditions (normal, fast, short, elevated; Table 1). A metronome was used during recording to pace the demonstrator's hand, but all clips were played silently during the experiment.

A single movement, the movement between locations 2 and 4 (the second and fourth targets, and the equivalent locations in the no-target clips) was selected for analysis. This movement type was presented eight times in each condition (presented 4 times from 2 to 4, and 4 times from

Fig. 1 Time-lapse diagram of experiment. Each trial began with a fixation cross, followed by a still image of a hand and a movie clip of a hand sequence. Participants imitated when the exclamation mark appeared. **a** Four yellow stickers acted as visual targets in the goal-directed condition. **b** In the goal-less condition, no stickers were visible, and the hand moved across the black table surface

Table 1 Movement features of the different stimuli

Target & No-target	Type	Speed (bpm)	Amplitude (mm)	Trajectory
T & NT	<i>Normal (N)</i>	48	150	<i>Flat</i>
	Fast (F)	58	150	Flat
	Short (S)	48	100	Flat
	Elevated (E)	48	150	Curved

The four movement ‘types’ are defined by the feature that differs from the other types (shown in bold). The baseline condition (termed ‘Normal’ (N)) is highlighted in italics

4 to 2). The 2–4 movement was selected because this was one of the larger movements, which meant there was more movement to be analysed and the hand action used a larger area onscreen, allowing eye movements to be measured more accurately. In addition, it was more difficult for participants to remember the location of targets in the goal-less clips since location 2 was not close to the periphery of the visual area (meaning that the screen/table edges could not be used as a reference point for the location).

Experimental Procedure

The experiment was split into four blocks, two containing target clips, and two containing no-target clips, and was run as shown in Fig. 1. Each trial started with a fixation cross that flashed green, and then a still image of the hand in the start position was displayed for 2,000 ms, immediately followed by a video clip of the movement. After observation of the clip, an exclamation mark appeared, at which point participants had to press the space bar to start recording their movement. Block order was counterbalanced across participants. Each block consisted of 24 trials; 16 trials containing the 2–4 movement, and 8 oddball trials containing different movement sequences, to reduce predictability and prevent the participant’s behaviour becoming repetitive and stereotyped. The different speed, amplitude and elevation conditions were randomly mixed within each block. Two catch trials per block were also introduced to keep the participant’s attention on the task, and contained a short black flash across the screen, which had to be noticed and verbally reported by the participants. All participants reported at least 85% of catch trials. At the start of the experiment, participants were instructed to ‘watch the video clip carefully and then copy what you saw as best you can’, no detail regarding the movements i.e. speed, height or movement changes, were given.

Eye Tracking

Where possible, eye movements were recorded using a head-mounted Eyelink II eye-tracker (SR research),

sampled at a frequency of 250 Hz with a resolution of 0.005°. Recording was performed for half of the experiment (2 blocks) to reduce possible discomfort. Blocks were counterbalanced across participants. Eye data were obtained from 6 ASD and 6 matched control participants.¹ Calibration was performed with both the standard system calibration, and with a custom made program written in Matlab (Mathworks Inc.). During the custom calibration, participants fixated on each of the target locations for 5 s, and this was conducted three times during the eye recording stage. This calibration allowed identification of gaze position co-ordinates at each target position, to determine gaze location during the experiment. Accuracy was within 1.91 ± 3.27 cm, estimated by comparing gaze location between subsequent calibrations.

Motor and Perceptual Control Tasks

All participants completed a perception task at the end of the testing session, to determine their ability to perceive movement changes. The test involved successively observing two movement clips, containing one move (i.e. 1–3). Half of the clip pairs were identical (i.e. the same clip shown twice), and half were the same movement but from two different conditions (e.g. one normal and one fast). Participants were required to make an un-speeded key-press response to indicate whether they thought the movements were the same or different. There were sixteen pairs of clips containing normal, fast, short and elevated movements, which were paired with either another clip of the same type (i.e. two of each fast–fast, elevated–elevated, short–short), or with a normal movement clip (i.e. two of each fast-normal, elevated-normal, short-normal). Four normal–normal clip pairs were included in the test for balance, but were not included in the analysis, as they acted as the ‘baseline’ condition for comparison to the other three conditions.

A tracing task was conducted at the end of the testing session to determine participants’ motor co-ordination skills, and to ensure that any fine motor impairment would not confound imitation ability. The task was simple and involved tracing three horizontal, and three vertical, straight lines, which were 100 mm in length. A Polhemus sensor was attached to the end of the pencil, to record movement during the task, and participants were given 10 s to complete each line.

¹ Eye tracking was attempted on all participants, but due to the difficulties in obtaining corneal reflection on participants wearing glasses, and with participant anxiety, data was not collected from all participants.

Data Analysis

Kinematic Data

Trials containing the 2–4 movement were identified for each participant and analysed using Matlab, R2007b (Mathworks Inc.). Movement data was filtered with a 120 Hz Butterworth filter and movement onset and offset times were determined when movement velocity rose above or fell below 10% of the peak velocity for six consecutive samples (48 ms). For each participant, the mean horizontal and vertical movement amplitude, duration, peak velocity and time to peak velocity was calculated in each condition. The accuracy of imitation was measured by the degree to which participants modulated their own movements according to the observed movements (i.e. how they adapted the speed of their movement to changes in speed of demonstrated movements). In order to identify when significant modulation occurred, difference scores were calculated for each movement parameter for the target and no target clips. For example, to measure the amount of modulation of movement duration and peak velocity, the difference was calculated between normal and fast trials (i.e. normal minus fast for duration, fast minus normal for peak velocity), resulting in positive values where the duration was longer in normal trials, and the velocity was

higher in fast trials (Fig. 2a). The averaged difference scores were compared to zero for each participant group using one-sample *t* tests.

Eye Data

Eye data was analysed using a custom-made program, written and run using Matlab, R2007b (Mathworks Inc.). Firstly, the program calculated the difference in the amount of time spent looking at targets 2 and 4, compared to between these two targets in percentage terms for each participant. The locations of targets 2 and 4 were obtained from the calibration, and areas of interest around the centre of the targets were set at ± 3 cm (approximately 1.5°). This value was chosen as visual acuity declines by about 50% 2° from the centre of the fovea (Jacobs 1979), and was well above our mean accuracy measure of 1.9 cm deviation from target centre. Due to the smaller sample size, all eye data analysis was carried out collapsed across the different speed, amplitude and elevation conditions. The difference in the amount of time spent looking *at* target areas and the time spent looking *between* targets was analysed using Mann–Whitney *U* tests. For the no-target clips the above values represented where the targets would have been located if present.

Fig. 2 **a** Mean ($\pm$ SEM) difference in duration between normal and fast trials. Positive values indicate fast trials had a shorter duration than normal trials. **b** Mean ($\pm$ SEM) difference in peak velocity between normal and fast trials. Positive values indicate fast trials had higher velocities than normal trials. **c** Mean ($\pm$ SEM) difference in

horizontal amplitude between normal and short trials. Positive values indicate short trials had shorter amplitudes than normal trials. **d** Mean ($\pm$ SEM) difference in vertical amplitude between normal and elevated trials. Positive values indicate elevated trials had greater vertical amplitude than normal trials

Secondly, the program identified three different eye movement types: saccades (greater than 1° , velocity greater than $15^\circ/\text{s}$ over 4 consecutive samples), fixations (less than $4.99^\circ/\text{s}$ for more than 4 consecutive samples) and smooth pursuit eye movements (greater than $5^\circ/\text{s}$ and less than, or equal to $50^\circ/\text{s}$). As fixation saccades can also reach velocities in the range of pursuit movements (Abadi and Gowen 2004), data segments of movements less than $15^\circ/\text{s}$ were analysed visually to check that fixation saccades and pursuit had been classified successfully. The duration of time spent performing each of the three classifications of movement types (saccade, fixation, and smooth pursuit) was calculated with any unmatched data labeled “unclassified”. A repeated measures ANOVAs group (ASD vs. Control) and clip condition (Target vs. No-target) was used to compare the percentage of time participants spent making these types of eye movement. We also calculated additional eye movement metrics including saccade number and amplitude, fixation and smooth pursuit duration. Examining these eye movement metrics provides information on the type of strategies that participant’s use when watching the clips, such as on how closely they follow the hand movement. For example, one would expect smaller and more frequent saccades, together with longer periods of pursuit in the case of closely following the stimulus.

Results

Kinematic Data

In target clips (goal-directed), neither the ASD nor the control group showed significant modulation of movement duration between normal and fast trials (ASD $t(15) = 0.604$, $p = 0.64$; control $t(15) = 0.349$, $p = 0.733$; Fig. 2a). In the no-target clips (goal-less), the ASD group again showed no significant modulation in movement duration ($t(15) = -1.205$, $p = 0.251$), however the control group did ($t(15) = 2.566$, $p = 0.025$). A similar pattern was observed for the modulation of peak velocity; the ASD group did not modulate their movement for either the target ($t(15) = 1.047$, $p = 0.313$), or the no-target clips ($t(15) = 0.136$, $p = 0.894$), whereas the control group displayed borderline significant modulation for target clips ($t(15) = 2.108$, $p = 0.054$), and significant modulation for no-target clips ($t(15) = 2.413$, $p = 0.03$; Fig. 2b);

To investigate the extent to which participants adjusted the size and trajectory of their own movements, differences were calculated between normal and short trials (normal minus short for horizontal amplitude), and normal and elevated trials (elevated minus normal for vertical amplitude; Fig. 2c, d). Both groups significantly modulated the size of their movement between normal and short trials in

both target and no target clips (ASD target: $t(15) = 4.718$, $p < 0.001$, ASD no-target: $t(15) = 7.621$, $p < 0.001$, Control target: $t(15) = 6.929$, $p < 0.001$ and Control no-target: $t(15) = 7.71$, $p < 0.001$).

The control group also demonstrated an ability to significantly modulate their movement between normal and elevated trials in both the target ($t(15) = 4.101$, $p = 0.001$), and the no-target clips ($t(15) = 5.133$, $p < 0.001$; Fig. 2d). Interestingly, the ASD group failed to modulate the vertical amplitude of their movement in target trials ($t(15) = 1.773$, $p = 0.098$), but succeeded in no-target trials ($t(15) = 2.808$, $p = 0.014$).

Eye Data

Firstly, we compared the time spent looking at targets with the time spent looking *between* targets. There was no significant difference between target and no-target clips for the ASD group ($U = 378$, $Z = -0.229$, $p = 0.819$), who displayed similar amounts of time on and between targets in both types of clip. The control group, however, showed a trend toward spending more time between targets in the target clips ($U = 194$, $Z = -1.938$, $p = 0.053$).

Fig. 3 Mean percentage of time ($\pm$ SEM) spent looking *at* targets 2 and 4 (black bars) and *between* targets 2 and 4 (white bars) in goal-directed and goal-less conditions **a** by the control group and **b** by the ASD group

Table 2 Percentage of time (rounded to nearest whole number $\pm$ SEM) during observation of movie clips spent fixating, making saccades, performing smooth pursuit, and data which could not be classified

	Saccades	Fixation	Smooth Pursuit	Unclassified
Control				
Target	6 $\pm$ 1	57 $\pm$ 7	31 $\pm$ 5	6 $\pm$ 2
No target	3 $\pm$ 1	31 $\pm$ 3	62 $\pm$ 3	4 $\pm$ 3
ASD				
ASD target	7 $\pm$ 1	79 $\pm$ 3	11 $\pm$ 3	3 $\pm$ 3
ASD no target	5 $\pm$ 1	71 $\pm$ 5	21 $\pm$ 5	5 $\pm$ 2

A between-group comparison indicated that the autistic group spent relatively more time on targets compared to between targets than the control group in both target ($U = 109$, $Z = 4.167$, $p < 0.001$) and no-target ($U = 230$, $Z = -1.946$, $p < 0.001$) clips (Fig. 3).

Repeated measures ANOVAs [group (ASD vs. Control) and clip type (Target vs. No-target)] were performed on the percentage of time that participants spent making saccades, fixations and smooth pursuit (Table 2). For saccades, there was a main effect of clip with more time being spent making saccades when the targets were present ($F(1, 23) = 20.432$, $p < 0.001$). There was also a main effect of group with the ASD group spending more time making saccades than the control group ($F(1,23) = 19.297$, $p < 0.001$). For smooth pursuit, there was a main effect of clip ($F(1,23) = 7.264$, $p < 0.001$), and group ($F(1,23) = -3.074$, $p = 0.049$): there was less pursuit in the target compared to no-target clips and the control group spent more time making pursuit movements. For the time spent fixating, there were also main effects of group ($F(1, 23) = 75.149$, $p < 0.001$) and clip ($F(1, 23) = 30.468$, $p < 0.001$), and a group $\times$ clip interaction ($F(1, 23) = 7.687$, $p = 0.01$). Further analysis revealed that the difference between the target and no target clips was larger for the control group than for the ASD group ($t(23) = 2.733$, $p = 0.011$).

Repeated measures ANOVAs [group (ASD vs. Control) and clip type (Target vs. No-target)] were also used to explore other eye movement metrics. For the average number of saccades per trial, there was a significant main effect of group ($F(1, 23) = 0.958$, $p = 0.034$) and clip ($F(1, 23) = 6.431$, $p = 0.018$) and a significant interaction between group $\times$ clip ($F(1, 23) = 40.55$, $p = 0.008$). Further analysis revealed that the ASD group made a higher number of saccades than the control group in the no-target clips ($t(23) = 5.142$, $p = 0.014$), whereas there was no difference between the groups in the presence of targets ($t(23) = 2.122$, $p = 0.124$). For the average amplitude of saccades, there were no significant effects

of group ($F(1, 23) = 0.187$, $p = 0.669$) or clip ($F(1, 23) = 1.381$, $p = 0.252$), but there was a significant interaction between group $\times$ clip ($F(1, 23) = 5.355$, $p = 0.003$). Further analysis showed that the average amplitude of saccades made by the ASD group in the no-target clips was significantly smaller than in the target condition ($t(23) = 2.58$, $p = 0.017$), but this was not true for controls ($t(23) = 1.176$, $p = 0.252$).

The average fixation duration while observing the movements was also calculated. There was no significant effect of group ($F(1, 23) = 0.088$, $p = 0.769$), but a significant effect of clip ($F(1, 23) = 6.89$, $p = 0.015$) and an interaction between group $\times$ clip ($F(1, 23) = 4.693$, $p = 0.041$) was found. Further tests revealed that fixations were significantly longer in target clips for the control group (629 ms target, 329 ms no-target, $t(23) = 2.613$, $p = 0.016$), but not for the ASD group (1,157 ms target, 1,029 ms no-target, $t(23) = 338$, $p = 0.739$).

The average duration of smooth pursuit was also explored, revealing a significant effect of group ($F(1, 23) = 15.42$, $p < 0.001$) and clip ($F(1, 23) = 85.33$, $p < 0.001$), and a significant interaction between group $\times$ clip ($F(1, 23) = 11.62$, $p = 0.002$). Further analysis indicated that the control group exhibited significantly longer episodes of pursuit than the ASD group in the no-target clips (Control 792 ms, ASD 303 ms, $t(23) = -4.425$, $p < 0.001$), but not in the target clips (Control 351 ms, ASD 157 ms, $t(23) = 847$, $p = 0.404$).

Perception Test

The number of incorrect responses was calculated for each participant and a 2×3 repeated measures ANOVA of factors group (ASD vs. Control) and condition (fast, short, elevated) was performed on the data (normally distributed, confirmed with Kolmogorov–Smirnov test, Table 3).

Table 3 Mean number of incorrect responses of participants during the perception test for 16 trials containing fast/normal, short/normal, and elevated/normal clip pairs, and mean standard deviation (mm) from the line during tracing in the motor task for three horizontal, and three vertical lines

Movement type	ASD	Control
Perception test		
Fast	2.7	2.5
Short	1.5	1.7
Elevated	0.4	0.6
Motor task		
Horizontal	0.53	0.62
Vertical	0.44	0.45

A significant effect of condition was found ($F(1, 15) = 60.323$, $p < 0.001$), but there was no significant effect of group ($F(1, 15) = 0.528$, $p = 0.479$) or interaction between condition and group ($F(1, 15) = 1.693$, $p = 0.22$). Further tests (collapsed across group), revealed that both groups gave more incorrect responses for fast trials than for both short ($t(15) = 3.674$, $p = 0.001$) and elevated trials ($t(15) = 10.599$, $p < 0.001$), and more incorrect responses were given for short than elevated trials ($t(15) = 5$, $p < 0.001$), i.e. incorrect responses fast > short > elevated.

Motor Task

Performance was measured using the average standard deviation from the traced line, averaged across groups (Table 3), and data was entered into a 2×2 repeated measures ANOVA of group (ASD, Control) and direction (horizontal, vertical). There was a borderline significant effect of direction of tracing with horizontal tending to be more accurate ($F(1, 15) = 4.228$, $p = 0.059$), but no significant difference between the groups ($F(1, 15) = 1.886$, $p = 0.191$), or significant interaction ($F(1, 15) = 1.424$, $p = 0.253$), showing that the ASD group had similar motor ability in this task to the control group.

Discussion

The aim of this study was to compare ASD and neurotypical participants during imitation of goal-directed and goal-less actions. Previous work has provided evidence for intact goal-directed imitation in autism, but an impaired ability to imitate actions that do not have a goal or are meaningless (Hamilton et al. 2007; Hobson and Lee 1999; Hobson and Hobson 2008; Rogers et al. 1996; Stone et al. 1997; Williams et al. 2004). The findings of the current work are in general agreement with these previous studies, but our examination of quantitative hand and eye movements have extended the understanding of imitation in ASD in several ways. It was predicted that in the absence of visual targets, the ASD group would fail to reflect movement changes between movement conditions, as a result of disrupted visuomotor mapping in the direct pathway for imitation. Indeed, the kinematic data for the speed trials showed that the control group modulated movement most successfully in the goal-less task, adjusting the speed of their movements between conditions, whereas the ASD group failed to modulate their speed. The control group reflected changes better when targets were absent, possibly because when targets were removed, there was a switch from goal-directed movement to direct visuomotor mapping. Conversely, the ASD group appeared to continue

with a goal-directed approach, even when the targets were absent.

Although eye movement data was only obtained from a sub-set of participants, it fits with the kinematic findings. In contrast to the autistic group, the control group spent significantly more time observing the movement between the targets, when targets were both present and absent and performed longer episodes of pursuit in the absence of targets. However, the ASD group spent overall more time making saccades and performed higher frequency, smaller amplitude saccades in the no-target clips, suggesting that they observe and process visual information in a different way to the control group. Vivanti et al. (2008) also observed different patterns of eye movements in autistic children during observation of either meaningless gestures, or meaningful actions involving objects that were subsequently imitated. The authors recorded the amount of time spent fixating the face or action area during observation of the actions. Overall, imitation was less accurate for the autistic children, particularly for meaningless actions and they spent less time fixating the face area during observation of meaningless gestures than the typical group, suggesting that different visual information was used by the two groups. These findings, together with the current results, highlight the importance of examining different eye movement strategies when considering imitation impairments in autistic individuals.

It is apparent that the ASD group adopted different patterns of eye movements, preferring to observe target areas as opposed to the movement and to use small saccades instead of pursuit. These eye tracking differences may have altered the amount of visual information available about the movement, decreasing imitation ability in the ASD group. Reduced visual sensitivity during saccades (Burr et al. 1994) would reduce the amount of visual information gained by the ASD group, which would impair reflection of speed changes. In contrast, the control group optimised the amount of information they received about the movement by making pursuit movements in the no-target clips; the increased extra-retinal input guiding eye velocity (Brenner and Berg 1994), and improved visual sensitivity during pursuit (Schutz et al. 2008) may have contributed to the success of the control group in modulating their movements. Nevertheless, we found that the ASD participants did increase the amount of pursuit they performed in the goal-less compared to goal-directed condition, despite failing to modulate their movements. This could indicate that they used information gained during smooth pursuit less effectively, or that there was still insufficient pursuit to gather enough information to produce speed changes. However, as our data were collapsed across conditions it is not possible to directly relate which aspect of imitation was affected by smooth pursuit.

Future work is necessary to ascertain whether these differences in eye movement strategy were responsible for the imitation results. Another caveat to our eye movement findings is that it was only possible to collect data from a small subset of participants, and for only half of the experimental blocks. As heterogeneity is well recognized in ASD, an improved approach for future studies would be to use a desk mounted eye tracker and correlate the eye and hand data for all participants.”

Surprisingly, the amount of time spent fixating between targets was greater for the target compared to no-target clips in the control group. This counterintuitive result can be explained by the presence of a target between targets 2 and 4, upon which the control group may have fixated and is supported by the findings of longer periods of fixation in the target condition.

Examination of changes in horizontal and vertical movement amplitude provided more insight into how control and neurotypical participants modulate their imitation strategy, revealing different findings to that of the speed data. For the horizontal trials, both the ASD and control group successfully altered the size of their movement in the presence and absence of goals. This had not been predicted, but it is likely that the observation of the end target in the goal-directed condition, or the movement end point in the goal-less condition, would have provided accurate visual cues as to the amplitude of the movement and therefore been incorporated into the goal that was imitated. These amplitude cues would have been available, despite the different observation strategies that the ASD (looking at the end-point) and control group (tracking of the movement) used prior to the movement endpoint. Furthermore, the movement end point is likely to have been more noticeable compared to the different speed conditions, as suggested by the results of the perception test.

During the vertical trials, the control group reflected vertical trajectory changes in both target and no-target trials, and showed increased pursuit of the hand, even when targets were present. This demonstrates that the control group are able to modulate the strategy they employ, depending on the nature of the observed movement, in order to imitate in the most effective and efficient way. This change in strategy may be due to the fact that in the elevated trials, the hand trajectory was very clearly different from the normal trajectory. In addition, the hand elevation was clearly unnecessary in order to reach the target. Therefore, the control participants may have placed more importance on this aspect and attempted to imitate it, suggesting that they are able to analyse the action and alter which aspects are important to imitate. These findings are supported by evidence that infants imitate irrational actions (e.g. turning on a switch with one’s head) only when there is no obvious reason (e.g. occupied hands, Brugger et al.

2007), suggesting that actions are analysed and interpreted before they are imitated. In contrast, the ASD group failed to reflect vertical trajectory changes when targets were present, but succeeded when targets were absent. This suggests that when visual targets are present, the ASD group retain them as the goal of the movement and continue to disregard kinematics, rather than analyzing the movement and changing imitation strategy. However when targets are absent, the obvious trajectory change is adopted as a goal, which subsequently leads to modulation of movement. Similarly, Hobson and Hobson (2008) noted that when the style of imitation was incidental and not necessary for successful imitation of the task, autistic but not neurotypical children were less likely to imitate the style. These findings are consistent with an impaired social function of imitation, where autistic individuals are less likely to engage in imitation of non-functional actions which mainly play a social role in shared experience (Rogers et al. 2010).

Overall, our results suggest that during goal-less imitation individuals with ASD do not imitate observed movement changes as accurately as neurotypical participants and adopt different patterns of eye movements. There are at least four possible reasons for these differences. Firstly, there is evidence for abnormal smooth pursuit in individuals with ASD (Takarae et al. 2004), which may have prevented ASD participants from tracking the hand and so favouring saccades and fixation of the targets. If smooth pursuit of the hand is disrupted, smaller saccades interspersed with fixations may be a compensatory mechanism to follow the hand to minimise loss of information, and ‘keep up’ (Karatekin 2007). As discussed earlier, this tracking strategy may have reduced the amount of visual information available and so affected imitation ability, although the role of eye movements in our imitation task requires further clarification.

Secondly, increased cognitive load during goal-less imitation may also affect the ability of the ASD group to modulate their movements. It has been shown that there is a reduced ability to process motion during high cognitive load (Rees et al. 1997). If the processing load during the no-target condition exhausts available capacity, irrelevant stimuli (or those deemed irrelevant) will not be perceived, and therefore not reflected. In the ASD group, it appeared that importance was placed on the start and end points of movement in both the target and no-target conditions—these are deemed the goals, and the ASD group successfully reflected start and end points in both. If less attention is paid to the hand while it is moving and load is at capacity, kinematic details may not be perceived. This is further supported by the eye movement findings; smaller saccades and longer fixations by the ASD group indicate a high processing load (Van Gog et al. 2009).

Thirdly, as goal-less imitation via the direct route may require greater visual and motor control, deficits within the perceptual or motor system may have contributed to reduced modulation of goal-less imitation. However, our data would suggest this is not the case as the ASD group had equivalent motor abilities to the control group, and detected speed changes successfully in the perception test. Nevertheless, as imitation of a moving hand may require greater sensorimotor demands than our tracing task, it still remains possible that deficits in motor planning and sensory feedback control (Cattaneo et al. 2007; Crane et al. 2009) favour imitation of known goals as opposed to movement kinematics.

Finally, the goal-directed strategy adopted by the ASD group may be a result of altered top-down control, guiding attention and eye movements towards the targets rather than towards the hand movement (Celani 2002; Kana et al. 2011). For example, it has been shown that while processing of non-human stimuli such as objects is normal, attending to and processing human stimuli appears abnormal in autistic individuals (Behrmann et al. 2006; Bird et al. 2006; Boucher and Lewis 1992; Dawson et al. 1998; Klin et al. 2009; Swettenham et al. 1998). In addition, Spengler et al. (2010) recently observed that autistic adults showed impaired top-down inhibition of automatic imitation in response to finger movements, highlighting that altered regulation of imitation may lead to imitation impairments in autistic people. Altered top-down regulation also fits with executive dysfunction in ASD that could account for the difficulty in changing strategy between goal-directed and goal-less actions. Such top down impairment is consistent with our findings for the vertical amplitude trials, where the control but not the ASD group changed their imitation strategy to favour the action over the goals. However, the ASD group were able to modulate imitation when the targets were absent, suggesting some degree of flexibility. Indeed, previous work has shown that explicit instructions can improve imitation performance in ASD (McIntosh et al. 2006), so the next step will be to investigate whether specific instructions to focus on the hand movement will result in modulation of imitation in the ASD group.

Conclusions

In conclusion, our findings support the growing consensus that imitation ability in autistic individuals dissociates between goal-directed and goal-less imitation, possibly as a result of a disrupted direct pathway for imitation. Importantly, our work has highlighted that altered imitation behaviour is also accompanied by changes in eye movements: in contrast to neurotypical participants, ASD

individuals spend more time fixating target locations and less time pursuing the observed movement during goal-less imitation. Future work is required to understand whether these different eye movement patterns directly affect imitation ability and to tease apart whether the goal-directed strategy adopted by individuals with ASD is due to sensorimotor integration demands involved in goal less imitation or to changes in top-down modulation of attention.

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