Research Article accepted in Autism Research on 21st October, 2018

Adults with Autism Spectrum Disorder are sensitive to the kinematic features defining natural human motion

Perception of biological kinematics in autism

Rosanna Edey[1], Jennifer Cook[2], Rebecca Brewer[3], Geoffrey Bird[4] and Clare Press[1*]

[1] Department of Psychological Sciences, Birkbeck, University of London

[2] School of Psychology, University of Birmingham

[3]Department of Psychology, Royal Holloway, University of London

[4]Department of Experimental Psychology, University of Oxford

Address: Department of Psychological Sciences, Birkbeck, University of London, Malet Street, London, England, WC1E 7HX

Telephone number: +44(0) 20 3073 8007; E-mail address: c.press@bbk.ac.uk

Acknowledgments

CP was supported by a Leverhulme Trust grant (RPG-2016-105) and GB by a project grant from the Baily Thomas Charitable Fund. We are grateful to Daniel Yon for advice concerning the analyses and Sarah Moore for help with testing.

Lay Summary

It has previously been suggested that autistic children and adults have problems perceiving the detailed manner in which others move – i.e., the subtle changes in speed as we move from point to point – which may impact on their ability to learn from, and about, others in a typical fashion. However, the results from the present two studies demonstrate that adults with autism can perceive this information, suggesting that atypicalities in processing others' movement may arise mainly as a consequence of atypical interpretation rather than perception.

Abstract

It has been hypothesized that individuals with Autism Spectrum Disorder (hereafter 'autism') have problems perceiving biological motion, which contributes to their social difficulties. However, the ability to perceive the kinematic profile characteristic of biological motion has not been systematically examined in autism. To examine this basic perceptual ability we conducted two experiments comparing adults with autism with matched typical adults. In Experiment 1, participants indicated whether two movements – which differed in the quantity of formula-generated biological motion – were the same or different. In Experiment 2, they judged which of two movements was 'less natural', where the stimuli varied in the degree to which they were a product of real movement data produced by autistic and typical models. There were no group differences in perceptual sensitivity in either experiment, with null effects supported by Bayesian analyses. The findings from these two experiments demonstrate that adults with autism are sensitive to the kinematic information defining biological motion to a typical degree – they are both able to detect the perceptual information in a same-different judgment, and as inclined to categorize biological motion derived from real models as natural. These findings therefore provide evidence against the hypothesis that individuals with autism exhibit low-level difficulties in perceiving the kinematics of others' actions, suggesting that atypicalities arise either when integrating this kinematic information with other perceptual input, or in the interpretation of kinematic information.

Keywords: Adults; Biological Motion; Social Cognition

Introduction

It has been proposed that those with Autism Spectrum Disorder (hereafter ‘autism’) have difficulties perceiving biological motion (see Kaiser & Pelphrey, 2012 for review). Difficulties with these lower level perceptual processes are suggested to generate a cascade of atypical social behavior, given that problems perceiving others will result in an inability to learn from, and about, them in the typical manner (Klin, Jones, Schultz, & Volkmar, 2003; Pavlova, 2012). For instance, difficulty perceiving biological motion may result in reduced attention towards others, and therefore a reduced ability to process the relevant cues signaling their internal states (Klin et al., 2003).

A range of studies have tested this theory by examining perception of ‘point-light walker’ stimuli in which lights signal the movement of major joints of the body during movement. Point-light stimuli therefore contain only low-level form and kinematic information (Johansson, 1973). In these studies, participants are required to identify the presence of a walker embedded within noise or relative to scrambled non-biological motion (Blake, Turner, Smoski, Pozdol, & Stone, 2003; Jones et al., 2011; Kaiser, Delmolino, Tanaka, & Shiffrar, 2010; Koldewyn, Whitney, & Rivera, 2010), or to assess the walking direction of the actor (Herrington et al., 2007; Freitag et al., 2008; McKay et al., 2012; Rutherford & Troje, 2011; Saygin, Cook, & Blakemore, 2010). Interestingly, studies specifically assessing these low-level perceptual abilities in adults with autism have typically found unimpaired performance relative to matched typical groups (note that more mixed results are found with children and adolescents; Blake et al., 2003; Cusack, Williams, & Neri, 2015; Jones et al., 2011; Kaiser, et al, 2010; Koldewyn et al., 2010).

Notably, however, these studies use tasks that could be performed using a range of perceptual cues. For instance, walking direction can be determined from point-light stimuli through perception of ‘local’ kinematic features (e.g., detection of the phasic kinematics of single points) or ‘global’ spatial-temporal features (e.g., grouping all the points into the human form and assessing their phasic relationships; see Dakin & Frith, 2005; Saygin et al., 2010), and recent evidence suggests that typical and autistic individuals (we use this term, as well as ‘individuals with autism’, as it is endorsed by many individuals from the autism community; see Kenny et al., 2016) use differential processing strategies when encoding these biological motion stimuli (van Boxtel, Dapretto, & Lu, 2016). Therefore, those with autism might feasibly have difficulties processing some of the perceptual information present in biological motion, but compensate for these difficulties by relying on a different source of perceptual input (Livingston & Happé, 2017).

A novel paradigm developed by Cook, Saygin, Swain, and Blakemore (2009) removed this ambiguity by presenting the biological kinematic profile without the form information. In this experiment adult participants were asked to judge which of two animated hand movements was ‘less natural’, where the movement consisted of a single point moving with different kinematic profiles. One movement was programmed to move with a formula-generated ‘minimum jerk’ profile, where the movement was slower at turning points relative to midpoints, as is characteristic of biological motion (Todorov & Jordan, 1998). The other moved with a linear combination of the minimum jerk profile and constant velocity – i.e., unnatural movement with no changes in acceleration. In contrast with the point-light walker literature, the autistic adults were less able to detect the profile that was more natural than matched typical participants. Therefore, this study indicates that those with autism may have a specific difficulty in perceiving the kinematic profile of biological motion.

However, there is more than one way in which to interpret this finding of reduced detection of ‘natural’ human motion in autism. First, those with autism may have a genuine perceptual insensitivity such that they are less able to detect biological motion. Second, given that the task required participants to judge the relative level of ‘natural’ motion in the two profiles, they may be sensitive to the kinematic information, but be less inclined to label the biological motion profile as natural. This effect may arise either if one has an inaccurate model of how humans typically move, or if – due to greater focus on perceptual details (e.g., Happé & Frith, 2006) or more ‘literal’ interpretation of task instructions (Martin & McDonald, 2004) – one is less willing to label a formula-generated biological motion profile as natural. The present experiments aimed to distinguish between these potential interpretations, using a similar paradigm to that employed by Cook et al. (2009). Experiment 1 tested whether adults with autism are equally able to detect biological motion without being required to label the kinematic profiles as natural or unnatural, by asking them simply to state whether two profiles were the same or different. Given that there was no evidence in Experiment 1 for deficits in the autism group, Experiment 2 subsequently addressed whether those with autism have a typical representation of what constitutes biological motion. Experiment 2 made one key change with respect to the study of Cook et al. (2009), by presenting profiles that were actor-generated rather than formula-generated.

Experiment 1

In Experiment 1 participants were presented with two animated hand movements and asked to judge whether they were the ‘same’ or ‘different’. We presented six equally spaced motion morph levels, ranging from 0% different (wherein the two animations were identical) to 100% different (wherein the animations were maximally different: one was 100% natural motion [minimum jerk] and the other was 100% unnatural [constant velocity: CV]). We determined participants’ sensitivity to the motion information by calculating *d’* at each motion morph level, which reflects the sensitivity to the difference between the animations, independent of any response bias (e.g., tendency to make 'same' judgments). If participants with autism have a reduced ability to perceive the kinematic information characterizing biological motion, they will exhibit lower *d'*s in this task relative to the typical group.

Method

Participants

Twenty adults with autism (15 males) and 17 typical adults (14 males) were recruited from the local research volunteer database. An opportunity sample was used – all those registered on our database of individuals wishing to be contacted to take part in research were contacted and we tested all who volunteered. The two groups were matched on Full-Scale IQ (FSIQ), as measured by the Wechsler Abbreviated Scale of Intelligence (WASI; *t*(35) = 1.33; *p* = 0.191), age (autism 18-69 years, typical 19-50 years, *t*(35) = -0.50; *p*=0.62) and gender (Fishers Exact Test, *p*=.70; see Table 1; the current studies tested low-level perceptual abilities that were not anticipated to differ between genders, so males and females were pooled). All participants in the autism group were diagnosed by an independent clinician, and the ADOS was administered by a trained researcher to assess current level of social functioning (see Table 1). All participants gave informed consent to take part in the study, which was approved by the local ethics committee and performed in accordance with the guidelines laid out in the 1964 Declaration of Helsinki. There were no outliers or participants excluded.

Stimuli

The stimuli were created in Matlab®. An image of a human hand was programmed to make a vertical sinusoidal movement of amplitude 110 mm and frequency 0.5 Hz. The images were identical to those employed in Cook et al. (2009, see Figure 1A). On each trial, two animations were presented: a ‘Motion Reference’ and a ‘Motion Morph’. Two Motion References were used. For the ‘Natural’ Motion Reference condition the reference stimulus moved with the constrained minimum jerk model (Todorov & Jordan, 1998). The model assumes that if $r(s) = [x(s), y(s), z(s)]$ is a 3D curve describing the path of the hand during a particular trial, where s is the distance along the path, and tangential speed is $s^{\bullet}(t)$ (where $s^{\bullet}$ is a time derivative, r' is the derivative with respect to s, and boldface signifies vector quantities), the temporal profile of the movement will minimize the scalar function:

$$J = \int_0^T \left\| \frac{d^3}{dt^3} \mathbf{r}[s(t)] \right\|^2 dt$$

For the ‘Unnatural’ Motion Reference condition the reference animation moved with constant velocity. The Motion Morph stimuli presented a linear combination of a minimum jerk and a constant velocity profile. The velocity morphs were calculated using the formula:

Motion Morph = p_1*(Natural Movement) +* p_2*(Unnatural Movement)*

where the p_1 weight determines the proportion of ‘natural’ movement in the trajectory, and the p_2 weight determines the proportion of the ‘unnatural’ movement profile. The ratio between the natural and unnatural weightings differed in steps of 20% to generate six motion morphs. There were 10 exemplars at each of the 6 motion morph levels (100%, 80%, 60%, 40%, 20% and 0% weighting of natural motion), resulting in 120 animation pairs in total (60 with the natural and 60 with the unnatural reference stimulus). For each participant, all trials were pseudo-randomized, such that a trial from the same condition did not occur more than twice in a row. The duration of the entire experiment was approximately 20 minutes, not including breaks.

Procedure

On each trial in the experiment, the participant was presented with a Motion Morph and a Motion Reference animation, which were presented in a random order and separated by a black screen for 1500 ms. Following the two animations, participants were asked to indicate using a button press whether the two animations were the ‘same’ or ‘different’. Prior to testing, each participant was read instructions by the experimenter and performed a practice task where they were required to make five correct consecutive responses comparing 100% and 0% stimuli (i.e., the easiest trials). Participants then completed the experiment in three blocks of 80 trials with rest breaks between blocks.

Data analysis

d’ = z(HR) – z(FAR), where z(HR) is the z score of the Hit Rate (proportion of ‘different’ responses when the stimuli were different, i.e., Motion Morph Level > 0%) and z(FAR) is the z score of the False Alarm Rate (proportion of ‘different’ responses when the two stimuli were identical, i.e., Motion Morph Level = 0%). *d’* was calculated for five Morph Levels (20%, 40%, 60%, 80%, 100%; the responses at the 0% Motion Morph level allow calculation of FAR), separately for the Natural and Unnatural motion reference conditions. For the analysis we compared the *d’* values for the relative ‘Kinematic Difference Levels’, which represented the difference in signal from the reference stimulus. Thus, a Kinematic Difference Level of 20% for the Natural Reference condition represents a Motion Morph that was 80% natural and 20% unnatural, whereas for the Unnatural Reference condition the 20% Kinematic Difference Level represents a Motion Morph that was 80% unnatural and 20% natural.

Results

A 2x2x5 mixed-model ANOVA was used to analyse the *d'* values, with Group (autism, typical) as a between-participants factor, and Motion Reference (Natural, Unnatural) and Kinematic Difference Level (20%, 40%, 60%, 80%, 100%) as within-participant factors.

There was a significant effect of Motion Reference ($F(1,35)=6.18$, $p=.018$, $\eta_p^2=.150$). Participants were more sensitive to differences between the stimuli when comparing a Motion Morph with a Natural Reference (M=.973, SEM=.140), than an Unnatural Reference (M=.733, SEM=.115). As expected, there was also a linear effect of the Kinematic Difference Level ($F(1,35)=94.34$, $p<.001$, $\eta_p^2=.730$), demonstrating that as the physical difference between the two stimuli increased, the ability to detect this difference also increased. There was additionally an interaction between Kinematic Difference Level and Motion Reference ($F(4,140)=7.21$, $p<.001$, $\eta_p^2=.171$), such that for the intermediate levels (40% and 60% kinematic differences) participants were more sensitive when comparing against a Natural Reference (40% M=.811, SEM=.143, $p=.010$; 60% M=1.10, SEM=.160, $p<.001$) relative to an Unnatural Reference (40% M=.36, SEM=.113; 60% M=.58, SEM=.137), but not for the other levels.

Critically for our main hypotheses, however, there was no main effect of Group ($F(1,35)=.025$, $p=.876$, $\eta_p^2=.001$, autism M=.872, SEM=.161; typical M=.834, SEM=.174), and none of the above effects interacted with Group (all Fs < 1.37, all ps > .25, see Figure 2A). Additionally, between-participant *t*-tests for each Kinematic Difference Level revealed no group difference at any level (levels 40-100%: all ts <.38, all ps>.700; see Figure 2A; at the 20% Kinematic Difference Level, where sensitivity was especially poor in both groups, the group difference approached a trend, $t(35)=1.68$, $p=.103$, which was driven by the typical group performing more poorly than the autism group). To examine whether the nonsignificant effect of group reflects evidence for comparable performance or a lack of statistical power, we calculated a Bayes Factor (BF_{10}), which represents the ratio of evidence for the alternative model over evidence for the null model. It is assumed that $BF_{10}<.33$ provides good evidence to support the null (Jeffreys, 1939; Lee & Wagenmakers, 2014). A Bayesian non-directional between-participants *t*-test in JASP on the mean scores in the autism and typical groups (centred on 0, $\gamma = 7.07$) indeed revealed evidence that the performance in the two groups was comparable ($BF_{10}= 0.319$; evidence in favour of the null is even stronger if a directional test is used, predicting the autism group's performance to be worse than the typical group's; $BF_{-0} = .288$; Love et al., 2015).

Discussion

In Experiment 1, we investigated whether adults with autism exhibit a reduced ability to detect biological motion in a simple same/different judgment task. This experiment demonstrated that the autism and typical groups were equally sensitive to biological motion.

Experiment 2

Experiment 1 suggests that individuals with autism are as able as typical individuals to perceive biological motion. However, previous studies investigating perception of the biological motion kinematic profile in autism have demonstrated lower performance when participants are asked to recognize natural movement (Cook et al., 2009). Therefore, it is possible that the reduced attention towards others throughout development in autism may result in atypical perceptual models used to categorize biological motion as 'human' or 'natural' (Klin et al., 2003). If biological motion is detected, but not correctly categorized as biological motion, this would likely generate a host of differences in social skills similar to those that would be expected if it is not detected. Experiment 2 therefore examined whether individuals with autism recognise biological motion as a natural human motion profile. As in Experiment 1, we presented participants with two profiles differing in their level of biological motion, but instead of being asked to judge whether they were the same or different, participants were asked which was the 'less natural'.

Given that the profile presented in Experiment 1 and Cook et al. (2009) was formula-generated, it is plausible that individuals with autism may be disinclined to label this profile as 'natural' because there are subtle differences between this profile and a realistic human movement. The profile was modelled on an equation that provides a fair approximation of human movement – i.e., one that minimizes jerk (Todorov, & Jordan, 1998) – but real human movement in fact contains a higher level of kinematic noise than this perfect minimum jerk profile (Figure 1). We therefore generated the profiles for Experiment 2 on the basis of real execution data in a task where adult participants were required to move their arm back and forth in a horizontal plane (Cook, Blakemore, & Press, 2013). Given that this action execution study demonstrated different kinematic profiles in adults with autism and matched typical adults (the autistic movements exhibited greater jerk; Cook et al., 2013, see also Edey et al., 2016; Figure 1B and C), Experiment 2 presented the average profiles of typical and autistic participants. This experiment therefore also enabled us to examine any differences in movement categorization between autistic and typical observers when presented with profiles from their 'own group' or the 'other group'.

We made two further methodological changes to our procedure. First, Experiment 1 presented a fixed set of stimuli to all participants and calculated d' at each kinematic difference level. Given that sensitivity was especially low in some conditions (see Figure 2) it was deemed preferable to use a staircase procedure (Kingdom & Prins, 2010), whereby kinematic differences were varied in each condition to establish the point at which participants could distinguish the stimuli, and therefore avoid presenting a large number of stimuli that a given participant was unable to distinguish. Second, given that all participants were more sensitive to kinematic perturbations in Experiment 1 when compared against a natural reference, Experiment 2 presented only natural reference stimuli and not unnatural references.

Materials and Methods

Participants

Thirty-one typical adults and 25 adults with autism were recruited from the local research volunteer database. Seven participants from the typical group and three participants from the autism group were excluded because their data for one (autism N=2, typical N=2) or more (autism N=1, typical N=5) of the four test staircases did not meet criteria to produce robust perceptual threshold estimations (see the Procedure section). These exclusions resulted in a final sample of 24 (23 males) typical participants and 22 (18 males) participants with autism. One (one male) of the typical participants and five (four male) of the autistic participants had also participated in Experiment 1 (note that exclusion of these participants did not influence the effects of group). An independent clinician diagnosed participants in the autism group, and the ADOS-2 was additionally administered to confirm participants' current level of functioning. Three participants did not meet all ADOS-2 criteria for classification of an Autism Spectrum Disorder. These participants were indistinguishable from the other participants on all measures, therefore data from all participants in the autism group are reported. The same pattern of results was found, however, when excluding those who did not reach the ADOS score criterion.

The participant groups were matched on FSIQ, as measured by the WAIS for the autism participants and the WASI for the typical group (*t*(44)=1.34, *p*=.186), age (autism 18-68 years, typical 19-50 years, *t*(32.86)=1.63, *p*=.121), and gender (Fishers Exact Test, *p*=.178), but, as expected, there was a significant difference between the groups in Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001) scores (*t*(44)=6.79, *p*<.001; see Table 2).

Stimuli

As in Experiment 1, the stimuli were created in Matlab® and used the same image of a hand. To generate the reference (natural) stimuli, for each profile (autism or typical) the mean x and y displacements of the actor groups' hand movements were used as the x and y co-ordinates at which to present the image of the hand. The motion morph stimuli presented a linear combination of reference stimuli and a constant velocity (unnatural) profile, calculated in the same way as described in Experiment 1. The initial motion morph stimulus at the beginning of each block contained a weighting of 100% unnatural motion and 0% natural (typical or autism) such that it was highly distinguishable from the reference stimulus. The weighting of the subsequent motion morph stimulus on each trial was calculated according to the participant's performance on the preceding trial (see Sensitivity Threshold Calculation).

Procedure

On each trial the participant was presented with a motion morph and a reference animation, presented in a random order and separated by a black screen for 1500 ms. Following the two animations, participants were asked to indicate with a button press which of the two hand movements was 'less natural' (see Figure 1D). Before the experiment, the experimenter read instructions to the participant, where natural movement was defined as how a person would typically move when moving their arm without expressing any emotion; and unnatural movement was defined as odd or mechanical movement.

To familiarize participants with the procedure and the stimuli they completed two practice mini-blocks of five trials for each condition (typical and autistic profiles), which were randomized across participants. The participants subsequently undertook the testing session, which consisted of 12 blocks. Each block contained 17 trials (total of 204 trials), and lasted approximately two minutes. Typical and autistic motion profile conditions were presented in separate blocks (six for each condition). The block type alternated and was randomized in pairs, such that participants never completed more than two blocks of the same condition in a row. The duration of the whole experiment was approximately 30 minutes.

Sensitivity Threshold Calculation

To measure each participant's sensitivity to the two types of natural movement we calculated their psychophysical threshold using a two-interval forced-choice adaptive staircase procedure. The ratio between natural and unnatural motion within the motion morph stimulus decreased linearly according to the participant's performance. The weighting of the motion morph stimulus was determined on a trial-by-trial basis, using a 'three-down, one-up' adaptive technique. In this procedure, three correct responses resulted in a step down the staircase (the unnatural weighting decreased and the natural weighting increased, thus the motion morph and reference became more perceptually similar, increasing difficulty). One incorrect response resulted in a step up the staircase (the unnatural weighting increased and the natural weighting decreased, thus the motion morph and reference became more perceptually distinct). This method aims to identify the 79.4% correct point on a psychometric function (in a two-choice method, the probability of moving down or up the staircase must be equal, so if the probability of moving up the staircase is p, then the probability of moving down must be equal to $p*p*p$, or .5, and hence the target probability of getting a correct response = 3√.5 =.0794 [Kingdom & Prins, 2010]).

Initially, the weighting change for either three successive correct, or one incorrect response, was 20% (hereafter a 'jump'). After four turning points on the staircase, these weighting 'jumps' were reduced to smaller 'steps' (step size = 2.5%) to allow for a finer estimation of the participant's threshold. At the start of the fourth block of each condition a new staircase started. Participants' perceptual sensitivity threshold was calculated as the mean proportion of unnatural movement present across all of the 'step' turning points for each staircase (see Garcia-Perez, 1998; note that similar results were obtained when averaging across only the last four step reversal points, e.g., Wetherill & Levitt, 1998). The estimates from the two staircases for each condition (autistic or typical models) were then averaged to obtain one estimate per condition (note that no effects interacted with 'block' and therefore we do not report this factor below). A lower threshold therefore represents greater sensitivity to the specific movement cues that define natural motion (i.e., better performance; note that this is in contrast to the d' measure used in Experiment 1, whereby better performance is indicated by higher values).

Participants who failed to transition from 'jumps' to 'steps' (i.e., had fewer than 4 turning points) on any staircase were excluded as it was not possible to generate a reliable threshold for their data (Kingdom & Prins, 2010).

Results

A 2x2 mixed ANOVA was performed on the sensitivity threshold data, with Group (autistic or typical observer) as a between-participants factor, and Model (autistic or typical movement profile) as a within-participants factor. There was no main effect of Group ($F(1,44)=0.81$, $p=.778$, $\eta_p^2=.002$) or main effect of Model ($F(1,44)=1.33$, $p=.255$, $\eta_p^2=.029$). There was an interaction between Model and Group ($F(1,44)=4.08$, $p=.049$, $\eta_p^2=.085$), driven by the typical group showing poorer sensitivity to the typical model than the autistic model ($p=.027$, 95%

CI [.008, .126], d=.420, autistic model: M=.68, SEM=.055, typical model: M=.75, SEM=.049) and the autism group showing equivalent, and relatively good, performance with both profiles (p=.551, 95% CI [-.027, .065], d=.106, autistic model: M=.70, SEM=.058, typical model: M=.68, SEM=.052, see Figure 2B). As in Experiment 1, we conducted a Bayesian non-directional between-participants t-test to compare the mean scores in the autism and typical groups, and determine whether the null effect reflects evidence for the null or inconclusive evidence (centred on 0, γ = 7.07). Again, this analysis revealed evidence favouring the null hypothesis, demonstrating that the overall performance in the two groups was indeed comparable (BF_{10}= 0.290; cf. BF_{-0}=.240, testing whether the autism group performed worse than the typical group) rather than indistinguishable due to a lack of power.

Discussion

Experiment 2 demonstrates that adults with autism label kinematic profiles derived from real human actors as ‘natural’, and that they are equally likely to do so as typical adults. These findings therefore provide evidence against the hypothesis that individuals with autism exhibit difficulties perceiving or correctly classifying human motion as ‘natural’.

We presented profiles derived either from real autistic or typical execution data and interestingly observed no own group benefit. Such a benefit may have been expected given the range of evidence that our perceptual models of action are tuned during development to our own actions (e.g., Edey, Yon, Cook, Dumontheil, & Press, 2017), likely either due to the role of the motor system in tuning perception (Press & Cook, 2015) or due to our vast visual experience with our own actions (Peelen & Downing, 2007). One possible explanation of the lack of own group advantage is that both groups have frequent experience of both types of movement profile and therefore consider both to represent ‘natural’ motion. Notably, the kinematic qualities of our movements can vary dramatically depending on our internal states (e.g., Roether, Omlor, Christensen, & Giese, 2009). Thus, although individuals with autism might generally move with greater jerk, they may frequently also produce movements that follow a more typical kinematic profile (e.g., when under-confident; Patel, Fleming, & Kilner, 2012). Likewise, a typical individual may occasionally produce movement kinematics that accord with the autistic profile (e.g., when in a state of greater social uncertainty typical individuals produce jerkier movements; Quesque, Lewkowicz, Delevoye-Turrell, & Coello, 2013). Consequently, due to the variability in action experiences across a range of settings, perceptual sensitivity to kinematic features that fall within both exemplar profiles might be equal.

Interestingly, the typical group exhibited *poorer* performance when observing the typical profile relative to the autistic profile. Of relevance here is that the autistic motion was in fact more physically distinct from the unnatural (CV) profile (see Figure 1B and C – the speed differential between end- and mid-points is higher and therefore more distinct from CV), and therefore perhaps is easier to distinguish from the unnatural profile compared to the typical profile. When the typical group made their judgments they might have been considering the range of other profiles presented throughout the experiment and making comparisons against these, such that the less kinematically-distinct typical profile became harder to detect (see van Boxel et al., 2016). Interestingly, the autism group did not show the same reduction in performance with the typical profile, perhaps explained by the lesser influence of context on their judgments (Lawson et al., 2014; Pellicano & Burr, 2012). Specifically, they may have made their judgments on a trial-by-trial basis, always identifying the action they saw to have the greater kinematic variation (i.e., greater changes in velocity and acceleration, or noise) as more natural (Tremoulet & Feldman, 2000).

The results of Experiment 2 may clarify the findings of Cook et al. (2009), where the autistic participants performed more poorly than the typical group on a similar motion perception task. A difference between these studies is that Cook et al. (2009) used formula-generated movements while the current study used kinematic trajectories of real movements. The formula-generated movements, which follow a perfectly smooth trajectory, may have been devoid of vital kinematic noise that provides a cue for naturalness (Tremoulet & Feldman, 2000). This absence of noise might have had a greater impact on the autistic group, given reports of perceptual attention to detail (Happé & Frith, 2006) and literal interpretations of task instructions (Martin & McDonald, 2004). It should be noted that Experiment 2 presented trajectories that were averaged over multiple participants and that would, therefore, have contained lower levels of noise than typical movements but which would, nevertheless, have been noisier than the trajectories presented by Cook et al. (2009; see Figure 1).

General Discussion

The findings from these two experiments demonstrate that adults with autism are sensitive to the kinematic information defining biological motion – they are both able to detect the perceptual information in a same-different judgment (Experiment 1), and are equally inclined to categorize it as natural (Experiment 2). These findings therefore provide evidence against the hypothesis that individuals with autism exhibit low-level difficulties in perceiving the kinematics of others' actions. The current findings are in line with other reports of intact biological motion processing in adults with autism (Herrington et al., 2007; Freitag et al., 2008; McKay et al., 2012; Rutherford & Troje, 2011; Saygin et al., 2010) and indicate that it is unlikely that individuals with autism compensate for difficulties in processing kinematic cues through reliance on other cues types (Livingston & Happe, 2017), as they demonstrated intact processing of kinematic cues when presented in isolation.

However, these studies should not be taken to reflect that all perceptual processing of others' actions is intact in autism. Recent evidence suggests that individuals with autism struggle with spatial-temporal integration (van Boxtel et al., 2016) and prediction (von der Lühe et al., 2016), and also when required to segregate motion signals from noise (Manning, Tibber, Charman, Dakin, & Pellicano, 2015). Therefore, despite sensitivity to the relevant biological kinematic signals within others' actions at a 'local' level, autistic individuals may have difficulty processing motion signals with a number of elements due to challenges combining cues – which vary in phase and kinematics – across space into a coherent signal (see also Dakin & Frith, 2005). Given these findings, it is worth noting that the present studies used videos that were derived from natural human motion, but where most cues had been removed to isolate perception of the human kinematic profile. These manipulations rendered stimuli that on many dimensions were in fact unnatural. If natural videos were presented – containing additional postural cues and kinematics cues from multiple points – it is possible that autistic individuals would exhibit greater difficulties. Additionally, the present study was conducted with adults. It was most appropriate to examine perception of the kinematics underlying biological motion in an adult population given that the only existing study to date that demonstrated difficulties with such perception used adult participants (Cook et al., 2009). However, given that we have found adult participants to be unimpaired in processing these perceptual cues, the same question should be addressed in children or adolescents with autism in order to test for delayed development of perceptual sensitivity to biological motion.

Interestingly, adults and children with autism have been shown to exhibit most consistent difficulties when ascribing affective or mental states to others (also referred to as 'mentalizing') on the basis of movement cues (Abell, Happé, & Frith, 2000; Atkinson, 2009;

(Bowler & Thommen, 2000; Castelli, Frith, Happé, & Frith, 2002; Di Cesare et al., 2017; Hubert et al., 2006; Jones et al., 2011; Klin, 2000; Moore, Hobson, & Lee, 1997; Nackaerts et al., 2012; Parron et al., 2008; White, Coniston, Rogers, & Frith, 2011; Zwickel, White, Coniston, Senju, & Frith, 2011). The present findings suggest that the increased mentalizing difficulties observed in these tasks are unlikely to be the result of a reduced ability to perceive the kinematic features of the human stimuli. It is possible that performance is especially disrupted in these mentalizing tasks due to representing more difficult mental state judgments (see Livingston & Happé, 2017 for review). However, it is also likely that those with autism find it especially difficult to interpret internal states from movement cues because of the differences in how they move themselves (Cook et al., 2013; Edey et al., 2016). Specifically, many internal states are conveyed via kinematic cues such as velocity, e.g., we move faster when we are feeling angry and more slowly when we are sad (e.g., Roether et al., 2009). Evidence suggests that we interpret these cues with reference to how we move ourselves, e.g., perceiving another as angry when the velocity of their movement reaches the range of velocities with which we move ourselves when angry (Edey et al., 2017). Therefore, individuals with autism and their typical counterparts may have different criteria for interpreting movement cues, leading to bidirectional communication difficulties (Edey et al., 2016), even if they are perceptually sensitive to the movement cues.

In conclusion, the present findings provide a systematic examination of the ability of adults with autism to perceive and categorize the kinematic profile characteristic of biological motion. Results demonstrate that adults with autism are unimpaired in this ability.

References

Abell, F., Happé, F., & Frith, U. (2000). Do triangles play tricks? Attribution of mental states to animated shapes in normal and abnormal development. *Cognitive Development*, *15*(1), 1–16. https://doi.org/10.1016/S0885-2014(00)00014-9

Atkinson, A. P. (2009). Impaired recognition of emotions from body movements is associated with elevated motion coherence thresholds in autism spectrum disorders. *Neuropsychologia*, *47*(13), 3023–3029. https://doi.org/10.1016/j.neuropsychologia.2009.05.019

Blake, R., Turner, L. M., Smoski, M. J., Pozdol, S. L., & Stone, W. L. (2003). Visual recognition of biological motion is impaired in children with autism. *Psychological Science*, *14*(2), 151–157. https://doi.org/10.1111/1467-9280.01434

Bowler, D. M., & Thommen, E. (2000). Attribution of Mechanical and Social Causality to Animated Displays by Children with Autism. *Autism*, *4*(2), 147–171. https://doi.org/10.1177/1362361300004002004

Castelli, F., Frith, H., Happé, F., & Frith, U. (2002). Autism, Asperger syndrome and brain mechanisms for the attribution of mental states to animated shapes. *Brain*, *125*(8), 1839–1849. https://doi.org/10.1093/brain/awf189

Cook, J. L., Blakemore, S.-J., & Press, C. (2013). Atypical basic movement kinematics in autism spectrum conditions. *Brain*, *136*(9), 2816–2824. https://doi.org/10.1093/brain/awt208

Cook, J. L., Saygin, A. P., Swain, R., & Blakemore, S.-J. (2009). Reduced sensitivity to minimum-jerk biological motion in autism spectrum conditions. *Neuropsychologia*, *47*(14), 3275–3278. https://doi.org/10.1016/j.neuropsychologia.2009.07.010

Cusack, J. P., Williams, J. H. G., & Neri, P. (2015). Action Perception Is Intact in Autism Spectrum Disorder. *Journal of Neuroscience*, *35*(5), 1849–1857. https://doi.org/10.1523/JNEUROSCI.4133-13.2015

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

Di Cesare, G., Sparaci, L., Pelosi, A., Mazzone, L., Giovagnoli, G., Menghini, D., … Vicari, S. (2017). Differences in Action Style Recognition in Children with Autism Spectrum Disorders. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.01456

Edey, R., Cook, J., Brewer, R., Johnson, M. H., Bird, G., & Press, C. (2016). Interaction takes two: Typical adults exhibit mind-blindness towards those with autism spectrum disorder. *Journal of Abnormal Psychology*, *125*(7), 879–885. https://doi.org/10.1037/abn0000199

Edey, R., Yon, D., Cook, J., Dumontheil, I., & Press, C. (2017). Our own action kinematics predict the perceived affective states of others. *Journal of Experimental Psychology: Human Perception and Performance*, *43*(7), 1263–1268. https://doi.org/10.1037/xhp0000423

Freitag, C. M., Konrad, C., Häberlen, M., Kleser, C., von Gontard, A., Reith, W., … Krick, C. (2008). Perception of biological motion in autism spectrum disorders. *Neuropsychologia*, *46*(5), 1480–1494. https://doi.org/10.1016/j.neuropsychologia.2007.12.025

Garcia-Perez, M.A. (1998). Forced-choice staircases with fixed step sizes: asymptotic and small-sample properties. *Vision Research, 38,* 1861-1881.

Happé, F., & Frith, U. (2006). The Weak Coherence Account: Detail-focused Cognitive Style in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *36*(1), 5–25. https://doi.org/10.1007/s10803-005-0039-0

Herrington, J. D., Baron-Cohen, S., Wheelwright, S. J., Singh, K. D., Bullmore, E. T., Brammer, M., & Williams, S. C. R. (2007). The role of MT+/V5 during biological motion perception in Asperger Syndrome: An fMRI study. *Research in Autism Spectrum Disorders*, *1*(1), 14–27. https://doi.org/10.1016/j.rasd.2006.07.002

Hubert, B., Wicker, B., Moore, D. G., Monfardini, E., Duverger, H., Fonséca, D. D., & Deruelle, C. (2006). Brief Report: Recognition of Emotional and Non-emotional Biological Motion in Individuals with Autistic Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *37*(7), 1386–1392. https://doi.org/10.1007/s10803-006-0275-y

Jeffreys, H. (1939). Theory of Probability. The Clarendon Press. Oxford, UK.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics*, *14*(2), 201–211. https://doi.org/10.3758/BF03212378

Jones, C. R. G., Swettenham, J., Charman, T., Marsden, A. J. S., Tregay, J., Baird, G., … Happé, F. (2011). No evidence for a fundamental visual motion processing deficit in adolescents with autism spectrum disorders. *Autism Research*, *4*(5), 347–357. https://doi.org/10.1002/aur.209

Kaiser, M. D., Delmolino, L., Tanaka, J. W., & Shiffrar, M. (2010). Comparison of visual sensitivity to human and object motion in autism spectrum disorder. *Autism Research*, *3*(4), 191–195. https://doi.org/10.1002/aur.137

Kaiser, M. D., & Pelphrey, K. A. (2012). Disrupted action perception in autism: Behavioral evidence, neuroendophenotypes, and diagnostic utility. *Developmental Cognitive Neuroscience*, *2*(1), 25–35. https://doi.org/10.1016/j.dcn.2011.05.005

Kenny, L., Hattersley, C., Molins, B., Buckley, C., Povey, C., & Pellicano, E. (2016). Which terms should be used to describe autism? Perspectives from the UK autism community. *Autism*, *20*(4), 442–462. https://doi.org/10.1177/1362361315588200

Kingdom, F., & Prins, N. (2010). *Psychophysics: A Practical Introduction* (1st ed.). London: Elsevier.

Klin, A., Jones, W., Schultz, R., & Volkmar, F. (2003). The enactive mind, or from actions to cognition: lessons from autism. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *358*(1430), 345–360. https://doi.org/10.1098/rstb.2002.1202

Klin, A. (2000). Attributing Social Meaning to Ambiguous Visual Stimuli in Higher-functioning Autism and Asperger Syndrome: The Social Attribution Task. *Journal of Child Psychology and Psychiatry*, *41*(7), 831–846. https://doi.org/10.1111/1469-7610.00671

Koldewyn, K., Whitney, D., & Rivera, S. M. (2010). The psychophysics of visual motion and global form processing in autism. *Brain*, *133*(2), 599–610. https://doi.org/10.1093/brain/awp272

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

Lee, M. D., & Wagenmakers, E.-J. (2014). Bayesian Cognitive Modeling: A Practical Course. Cambridge University Press. Cambridge, UK.

Livingston, L. A., & Happé, F. (2017). Conceptualising Compensation in Neurodevelopmental Disorders: Reflections from Autism Spectrum Disorder. *Neuroscience & Biobehavioral Reviews*. https://doi.org/10.1016/j.neubiorev.2017.06.005

Love J., Selker, R., Marsman, M., Jamil, T., Verhagen, A. J., Ly, A., et al. (2015). JASP (Version 0.7.1.12)

Manning, C., Tibber, M. S., Charman, T., Dakin, S. C., & Pellicano, E. (2015). Enhanced Integration of Motion Information in Children With Autism. *Journal of Neuroscience*, *35*(18), 6979–6986. https://doi.org/10.1523/JNEUROSCI.4645-14.2015

Martin, I., & McDonald, S. (2004). An exploration of causes of non-literal language problems in individuals with Asperger Syndrome. *Journal of Autism and Developmental Disorders*, *34*(3), 311–328.

McKay, L. S., Simmons, D. R., McAleer, P., Marjoram, D., Piggot, J., & Pollick, F. E. (2012). Do distinct atypical cortical networks process biological motion information in adults with Autism Spectrum Disorders? *NeuroImage*, *59*(2), 1524–1533. https://doi.org/10.1016/j.neuroimage.2011.08.033

Moore, D. G., Hobson, R. P., & Lee, A. (1997). Components of person perception: An investigation with autistic, non-autistic retarded and typically developing children and adolescents. *British Journal of Developmental Psychology*, *15*(4), 401–423. https://doi.org/10.1111/j.2044-835X.1997.tb00738.x

Nackaerts, E., Wagemans, J., Helsen, W., Swinnen, S. P., Wenderoth, N., & Alaerts, K. (2012). Recognizing Biological Motion and Emotions from Point-Light Displays in Autism Spectrum Disorders. *PLoS ONE*, *7*(9), e44473. https://doi.org/10.1371/journal.pone.0044473

Parron, C., Da Fonseca, D., Santos, A., Moore, D., Monfardini, E., & Deruelle, C. (2008). Recognition of biological motion in children with autistic spectrum disorders. *Autism*, *12*(3), 261–274. https://doi.org/10.1177/1362361307089520

Patel, D., Fleming, S. M., & Kilner, J. M. (2012). Inferring subjective states through the observation of actions. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1748), 4853–4860. https://doi.org/10.1098/rspb.2012.1847

Pavlova, M. A. (2012). Biological Motion Processing as a Hallmark of Social Cognition. *Cerebral Cortex*, *22*(5), 981–995. https://doi.org/10.1093/cercor/bhr156

Peelen, M. V., & Downing, P. E. (2007). The neural basis of visual body perception. *Nature Reviews Neuroscience*, *8*(8), 636–648. https://doi.org/10.1038/nrn2195

Pellicano, E., & Burr, D. (2012). When the world becomes ‘too real’: a Bayesian explanation of autistic perception. *Trends in Cognitive Sciences*, *16*(10), 504–510. https://doi.org/10.1016/j.tics.2012.08.009

Press, C., & Cook, R. (2015). Beyond action-specific simulation: domain-general motor contributions to perception. *Trends in Cognitive Sciences*, *19*(4), 176–178. https://doi.org/10.1016/j.tics.2015.01.006

Quesque, F., Lewkowicz, D., Delevoye-Turrell, Y. N., & Coello, Y. (2013). Effects of social intention on movement kinematics in cooperative actions. *Frontiers in Neurorobotics*, *7*. https://doi.org/10.3389/fnbot.2013.00014

Roether, C. L., Omlor, L., Christensen, A., & Giese, M. A. (2009). Critical features for the perception of emotion from gait. *Journal of Vision*, *9*(6), 15–15. https://doi.org/10.1167/9.6.15

Rutherford, M. D., & Troje, N. F. (2011). IQ Predicts Biological Motion Perception in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *42*(4), 557–565. https://doi.org/10.1007/s10803-011-1267-0

Saygin, A. P., Cook, J., & Blakemore, S.-J. (2010). Unaffected Perceptual Thresholds for Biological and Non-Biological Form-from-Motion Perception in Autism Spectrum Conditions. *PLoS ONE*, *5*(10), e13491. https://doi.org/10.1371/journal.pone.0013491

Todorov, E., & Jordan, M. (n.d.). Smoothness maximization along a predefined path accurately predicts the speed profiles of complex arm movements. *Journal of Neurophysiology*, *80*(2), 696–714.

Todorov, E., & Jordan, M. I. (1998). Smoothness maximization along a predefined path accurately predicts the speed profiles of complex arm movements. *Journal of Neurophysiology*, *80*(2), 696–714.

Tremoulet, P. D., & Feldman, J. (2000). Perception of animacy from the motion of a single object. *Perception*, *29*(8), 943–951. https://doi.org/10.1068/p3101 van Boxtel, J. J. A., Dapretto, M., & Lu, H. (2016). Intact recognition, but attenuated adaptation, for biological motion in youth with autism spectrum disorder: Reduced Global Biological Motion Adaptation in ASD. *Autism Research*, *9*(10), 1103–1113. https://doi.org/10.1002/aur.1595

von der Lühe, T., Manera, V., Barisic, I., Becchio, C., Vogeley, K., & Schilbach, L. (2016). Interpersonal predictive coding, not action perception, is impaired in autism. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(20150373), 1–8.

White, S. J., Coniston, D., Rogers, R., & Frith, U. (2011). Developing the Frith-Happé animations: A quick and objective test of Theory of Mind for adults with autism. *Autism Research*, *4*(2), 149–154. https://doi.org/10.1002/aur.174

Wetherill, G.B., & Levitt, H. (1965). Sequential estimation of points on a psychometric function. *The British Journal of Mathematical and Statistical Psychology, 18,* 1-10.

Zwickel, J., White, S. J., Coniston, D., Senju, A., & Frith, U. (2011). Exploring the building blocks of social cognition: spontaneous agency perception and visual perspective taking in autism. *Social Cognitive and Affective Neuroscience*, *6*(5), 564–571. https://doi.org/10.1093/scan/nsq088

Table 1: Demographic information for Typical and Autism Groups for Experiment 1

	FSIQ Mean (SEM)	Age Mean (SEM)	Gender (male)	ADOS Mean (SEM)
Autism Group (n=20)	115.53 (3.02)	41.10 (2.71)	15	9.76 (.83)
Typical Group (n=17)	118.24 (2.16)	38.76 (4.00)	14	-

Note that ADOS data were not obtained for one autism participant

Table 2: Demographic information for Typical and Autism Groups for Experiment 2

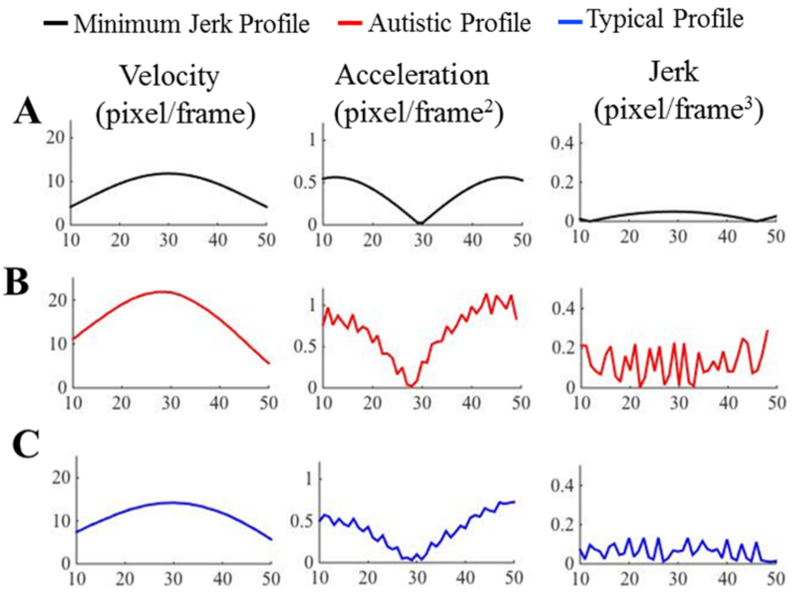
	FSIQ Mean (SEM)	Age Mean (SEM)	Gender (male)	AQ Mean (SEM)	ADOS Mean (SEM)
Autism Group (n =22)	111.18 (3.27)	36.77 (3.02)	18	32.77 (1.91)**	9.86 (.782)
Typical Group (n =24)	105.46 (2.77)	31.21 (1.68)	23	17.58 (1.41)	-

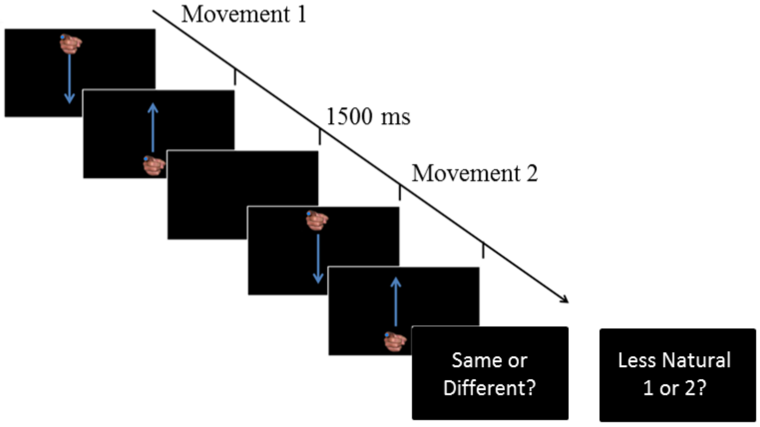
***p*<.001

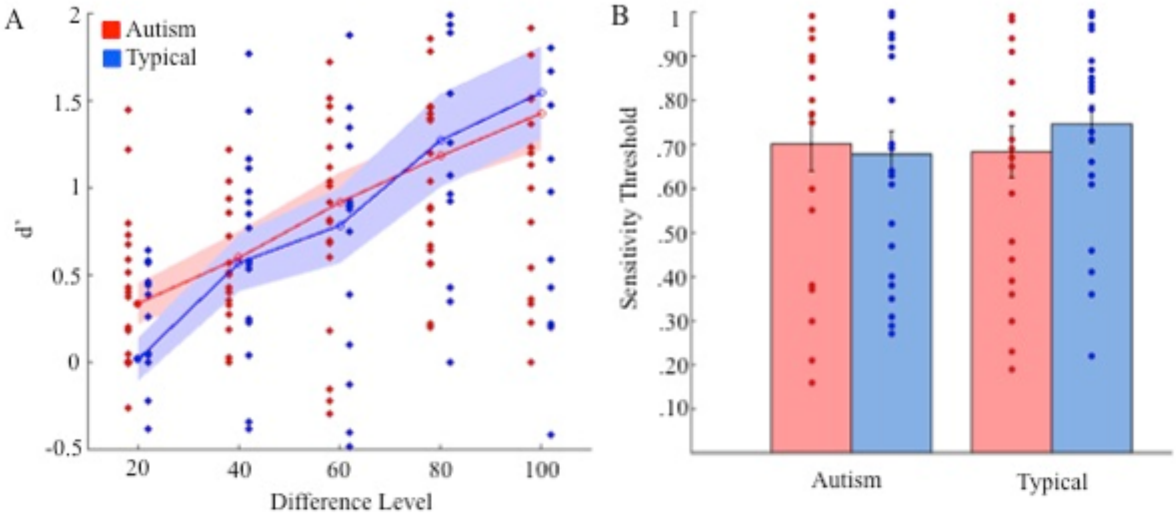
Figure legends

Figure 1: Top Panel: Example kinematic trajectories for one direction of movement used by Cook et al. (2009) and Experiment 1 (A), and the autism profile (B) and typical profile (C) used in Experiment 2. The first column denotes the velocity (pixels/frame) within each profile, the middle column denotes acceleration (pixels/frame^2), and the last column denotes jerk (pixels/frame^3). Note that the typical and autistic profiles, generated from real execution data, follow a profile that generally complies with the minimum jerk profile (bell-shaped velocity) but the signal is noisier. Bottom Panel: Schematic representation of a trial within the two experiments. In Experiment 1 participants were asked to identify whether the two profiles were the same or different, and in Experiment 2 participants identified which of the two movements was 'less natural'.

Figure 2: (A) Experiment 1. Mean d' scores for the autistic and typical participants at each kinematic difference level. Error bars represent SEM. Individual points represent performance for each participant. This graph demonstrates that both groups exhibited greater sensitivity as the physical difference between the stimuli increased, but there were no group differences in performance. (B) Experiment 2. Perceptual sensitivity thresholds (79.4% accuracy) for the autism and typical groups when observing autistic and typical movements. Lower thresholds indicate that participants have greater sensitivity (in contrast with the *d*'s in Experiment 1). Like in Experiment 1, there was no sign of impaired performance in the autism group.


Minimum Jerk Profile
Autistic Profile
Typical Profile
Velocity (pixel/frame)
Acceleration (pixel/frame²)
Jerk (pixel/frame³)
A
B
C
0
10
20
0
0.5
1
0
0.2
0.4
10
20
30
40
50


Movement 1
1500 ms
Movement 2
Same or Different?
Less Natural 1 or 2?


A
🟥 Autism
🟦 Typical
d'
Difference Level
20
40
60
80
100
-0.5
0
0.5
1
1.5
2
B
Sensitivity Threshold
1
.90
.80
.70
.60
.50
.40
.30
.20
.10
Autism
Typical