Journal of Abnormal Psychology
2016, Vol. 125, No. 7, 879–885

0021-843X/16/$12.00 http://dx.doi.org/10.1037/abn0000199

BRIEF REPORT

Interaction Takes Two: Typical Adults Exhibit Mind-Blindness Towards Those With Autism Spectrum Disorder

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Recent work suggests that we are better at interpreting the movements of others who move like us, and that individuals with Autism Spectrum Disorder (ASD) move in a quantifiably different way from typical individuals. Therefore, "social impairments" exhibited by individuals with ASD may, at least in part, represent a failure by typical individuals to infer the correct mental states from the movements of those with ASD. To examine this possibility, individuals with ASD and typical adults manually directed 2 triangles to generate animations depicting mental state interactions. Kinematic analysis of the generated animations demonstrated that the participants with ASD moved atypically, specifically with increased jerk compared to the typical participants. In confirmation of our primary hypothesis, typical individuals were better able to identify the mental state portrayed in the animations produced by typical, relative to autistic, individuals. The participants with ASD did not show this "same group" advantage, demonstrating comparable performance for the 2 sets of animations. These findings have significant implications for clinical assessment and intervention in ASD, and potentially other populations with atypical movement.

General Scientific Summary
Much research has suggested that people with autism struggle to read the mental states of others (without autism), but previous work has not investigated how well typical individuals recognize autistic mental states. Our novel design examines understanding of individuals both with and without autism by individuals with and without such a diagnosis. Our study suggests that communicative problems exhibited by individuals with autism may, in part, reflect a failure by typical individuals to infer the mental states of those with autism.

Keywords: Autism Spectrum Disorder, expertise, action perception, theory of mind

Supplemental materials: http://dx.doi.org/10.1037/abn0000199.supp

Medical professionals, such as general practitioners and mental health specialists, are frequently required to judge the emotional and mental states of their patients. They will likely make these judgments on the basis of several cues, including the patient's verbal report, facial expressions, postures, and importantly, the way that the patient moves. The kinematics of our movements

This article was published Online First September 1, 2016.
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We are grateful to Meredith Leston and Lia Antico for help with testing, and Alex Chamberlain for assistance in video editing.
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provide crucial information about our underlying mental and affective states. For example, higher velocity movements reflect greater confidence (Fleming, Weil, Nagy, Dolan, & Rees, 2010), whereas fast and accelerated movements often reflect anger (Roether, Omlor, Christensen, & Giese, 2009). Thus, in the same way that perception of a smile prompts the automatic attribution of happiness, perception of fast and accelerated movements, for example, prompt the attribution of anger (e.g., Atkinson, Tunstall, & Dittrich, 2007). Association of specific movement cues with specific mental and affective states provides a rapid route for the attribution of mental and affective states to others, helping clinicians to detect pain and distress, as well as friends to offer comfort in times of need, and juries and judges to distinguish deception from sincerity. It has therefore been proposed that perception of such movement cues is the initial step required for a whole host of sociocognitive processes, including theory of mind, that enable rapid and appropriate responses to others (Klin, Jones, Schultz, & Volkmar, 2003).

However, given that mental states are hidden, perfectly accurate inferences are unlikely to be made. One variable that is likely to determine the degree of accuracy is whether we move in a similar way to the observed party. Our experiences with the world tune our perceptual systems (Blakemore & Cooper, 1970; Sangrigoli, Pallier, Argenti, Ventureyra, & De Schonen, 2005), and we have extensive experience with our own actions as we learn to control them (Rochat, 1998; Van der Meer, Van der Weel, & Lee, 1995; White, Castle, & Held, 1964). This experience may tune our perceptual models of action according to how we move, both through direct visual tuning from self-observation and motor contributions to perception (Gerson, Bekkering, & Hunnius, 2015; Hunnius & Bekkering, 2014). Therefore, the way in which we execute actions is likely to have dramatic implications for our understanding of others, such that we may be better placed both to interpret and interact with others who move more like us.

We have recently observed that those with Autism Spectrum Disorder (hereafter "autism") move differently—specifically, with greater jerk, acceleration, and velocity—relative to typical individuals (Cook, Blakemore, & Press, 2013). This finding raises the possibility that typical individuals experience difficulty interpreting the actions of individuals with autism, in the same way that those with autism have problems interpreting (e.g., Nackaerts et al., 2012) and predicting (von der Lühe et al., 2016) typical movements. If action models tuned by developmental experience of one's own movements support the recognition of others' mental and affective states, then typical individuals, with typical action models, should be impaired when using atypical movement cues to interpret the mental and affective states of individuals with autism. Under this hypothesis, interaction difficulties between typical and autistic[1] individuals may be attributable to both parties; typical individuals may make less accurate mental state attributions about individuals with autism (demonstrate "mind-blindness") in the same way that individuals with autism appear to display mind-blindness toward typical individuals. Importantly, if individuals with autism move similarly to each other but dissimilarly to typical individuals, this hypothesis may help to explain why high-functioning individuals with autism describe social interactions with other autistic individuals as less effortful and more efficient than interactions with nonautistic people (Schilbach, 2016).

Much research has investigated how well those with autism are able to understand typical individuals, but surprisingly, how well typical individuals understand those with autism has received little attention. Mental state attribution difficulties in typical individuals would not simply be of academic interest. Medical, legal, and educational professionals frequently make judgments about the intentions and affective states of the individuals with whom they work, which influence diagnosis, sentencing, and intervention planning. If typical individuals in these roles are required to judge the mental and affective states of autistic individuals without appropriate models of their movements, errors are likely to be made with significant impact on the well-being of autistic individuals. It is therefore crucial to consider whether typical individuals have difficulties interpreting the actions of those with autism.

The present study investigated whether typical individuals are impaired at interpreting the movements produced by autistic, relative to typical, individuals, as well as investigating the performance of individuals with autism when observing both groups' movements. We used the Frith-Happé animation task, as it has been used widely in autism research to assess mental state attribution (Abell, Happé, & Frith, 2000; Heider & Simmel, 1944). The standard version of this task presents animations of two triangles moving on a computer monitor, designed by a nonautistic graphic artist to depict either mental states or random inanimate movement. Typical children and adults spontaneously attribute appropriate mental states to the former animation types more readily than those with autism (e.g., Abell et al., 2000; Castelli, Frith, Happé, & Frith, 2002). For the present experiment, participants with and without a diagnosis of autism were asked to direct hand-held triangular magnets on a table top to represent the same mental state verbs as used in the standard paradigm (coaxing, mocking, seducing, and surprising). In a perceptual task several months later, participants watched the animations and rated the extent to which they depicted each of these target mental states (note that participants never observed their own generated animations). We compared the accuracy of ratings in the perception task when typical and autistic participants observed both typical and autistic animations, to investigate the novel question of whether typical individuals exhibit specific difficulties when interpreting the movements of those with autism.

Materials and Methods

Participants

Twenty-five typical adults and 23 adults with autism were recruited from the local research volunteer database for the perceptual task (see Supplementary Methods for information relating to those participants who generated the animations). An opportunity sample was used—We contacted all those registered on the database and tested all who volunteered. An independent clinician diagnosed participants in the autism group according to *DSM–IV* criteria (American Psychiatric Association, 2000), and the

[1] The term "autistic people" is the preferred language of many individuals on the spectrum (see Sinclair, 2013). In this article, we use this term as well as person-first language (such as "individuals with autism") to respect the wishes of all individuals on the spectrum.

ADOS-2 (Autism Diagnostic Observation Schedule – 2; Lord et al., 2012) was administered to confirm participants' current level of functioning. Three participants did not meet all ADOS-2 criteria for a classification of autism spectrum disorder. These participants were indistinguishable from the other participants on all measures and therefore data from all autistic participants are reported, but the same pattern of results was found when excluding these three participants. Two participants (one participant from each group) were excluded from analysis as their verbal responses suggested that they did not understand the task demands. The remaining participants were matched on FSIQ [full scale IQ], $t(44) = .05$, $p = .964$, age (autism 19–69 years, typical 23–74 years, $t(44) = .63$, $p = .531$), and gender (Fisher's exact test, $p = .702$), and as expected, the groups differed significantly in AQ [Autism-Spectrum Quotient] scores, $t(44) = 5.98$, $p < .001$; see Table 1. All participants gave informed consent, and procedures received local ethical approval. All data were collected in accordance with the guidelines laid out in the 1964 Declaration of Helsinki.

Animation Generation and Kinematic Analysis

A white table with a black enclosure was used as the background for the animations (see Figure 1). A large red and a small blue triangle made from colored card were attached to two magnets; the opposite pole of the magnet was attached below the table to enable manual operation of each triangle. Participants were given time to practice operating the magnets to maneuver the triangles, and had two practice trials (see Figure 1A; note that they could see their action effects in the form of the triangle movements). A video camera (Panasonic SDR-S50) was positioned directly above the table to film the participants' animations at a rate of 25 frames/second.

The four target mental state words (coaxing, mocking, seducing and surprising—the same as used in Abell et al., 2000) were presented to participants in a random order. On each trial the participants were asked, "How will you represent (coaxing, mocking, seducing, surprising) with the two triangles?" Participants were instructed that their animations should last ~30 seconds, and given one minute to think before providing a verbal response of how they would animate the mental state word. Participants were directed to the dictionary definition if they were unsure of the word's meaning, and no further guidance was given. A follow-up study demonstrated that independent typical participants could understand the descriptions given by autistic and typical participants equally well (see Supplementary Methods). Following the verbal response the participants performed their animation. Each animation was edited to make size and colors consistent using Adobe After Effects (see Figure 1B, and Supplementary Video 1 for an example video). Any items that appeared on the screen, other than the triangles, were edited out (e.g., participants' heads).

The animations were analyzed using MATLAB to extract the kinematics (jerk, acceleration, and velocity) of both triangles. First, every pixel (720 × 576 pixels) within each frame was coded for the presence of red or blue and saved as a color-coded frame set. The following analysis was run twice to code the location of the red and blue triangle separately.

The color-coded frame sets were scanned to locate the four most extreme points of the triangles (top, bottom, left, and right). Two of these points related to the same corner of the triangle, and therefore one was removed. From the remaining three points, the "nose" of the triangle was located by identifying the adjoining point at the end of the two longest sides. The "tail" was the midpoint between the other two points. This procedure resulted in location markers for the nose and tail of the red and blue triangle on each frame. The change in x and y position was tracked between each frame by first order differentiation of the position vectors. These vectors were low pass Butterworth filtered at 2Hz to remove noise associated with the imperfect localization of the x and y values on some frames due to occasional poor contrast. The velocity was calculated as the square root of the summed squared x and y displacement per frame. The velocity values were then low pass Butterworth filtered at 3Hz to remove noise due to the imperfect measure of displacement of the nose/tail owing to occasional flickers in the animations due to extreme exposure in some of the frames. It was verified manually that filters were optimal in both preserving the movement information and removing noise. Visual inspection determined that frames with velocity values below 1 pixel/frame were periods of no movement, and were removed from further calculations. Acceleration was calculated as the absolute first order differential of the velocity vectors, and jerk was calculated as the absolute second order differential. The mean velocity, acceleration, and jerk was calculated from these absolute values, and transformed from pixels/frame to mm/second.

Animations were selected for the perceptual task based on two criteria. First, we selected two animations above and two below the mean jerk value for that group (e.g., autism) and target mental state (e.g., mocking), all within one standard deviation of the mean, and two animations greater than one standard deviation from the mean (one above and one below the mean). Second, we included a maximum of three animations created by any given participant. These criteria were employed to match the jerk of the selected stimulus set to the distribution of the full sample of generated animations (see Figure 2A). Further details of the animation selection are included in Supplementary Methods.

Procedure

The experiment was run via MATLAB on a 24" computer screen. An initial practice trial familiarized participants with the

Table 1
Demographic Information For Autistic and Typical Participants In The Perceptual Task

Perceiver group	FSIQ mean (SEM)	Age mean (SEM)	Gender male	AQ mean (SEM)	ADOS mean (SEM)
Autism (n = 22)	111.05 (3.62)	38.50 (2.97)	19	32.82 (2.11)**	9.77 (.79)
Typical (n = 24)	111.25 (2.69)	36.08 (2.45)	19	17.29 (1.56)	—

** $p < .001$.

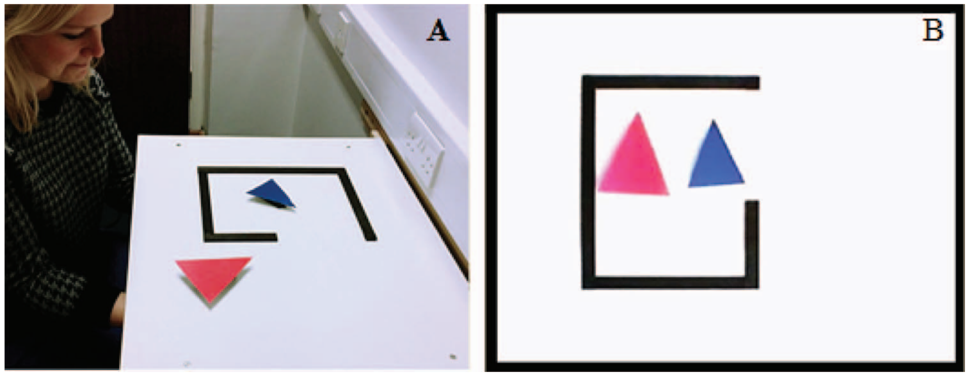

Figure 1. (A) Participants generated animations by manually directing triangles on a table top with magnets to represent the target mental state words (coaxing, mocking, seducing, and surprising). (B) Edited example stimulus that was displayed to participants as a ~30 second animation. See the online article for the color version of this figure.

procedure and task requirements. On each trial, after viewing the animation, participants were asked to describe verbally what happened in the animation, to ensure that they had attended to the whole animation. Following the verbal response, they were asked to rate on a visual analogue scale (ranging from 1 [*not at all*] to 50 [*a lot*]) the extent to which the animation depicted the four target mental state words: coaxing, mocking, seducing, and surprising. Participants were able to rate the four target mental state words in any order and could change their responses at any point before pressing a key to begin the next trial. No feedback was given. Six autistic and six typical animations of each of the four mental state words were presented, resulting in 48 animations. Participants who took part in both the animation generation and the perceptual task were not shown their own animations (see Supplementary Methods).

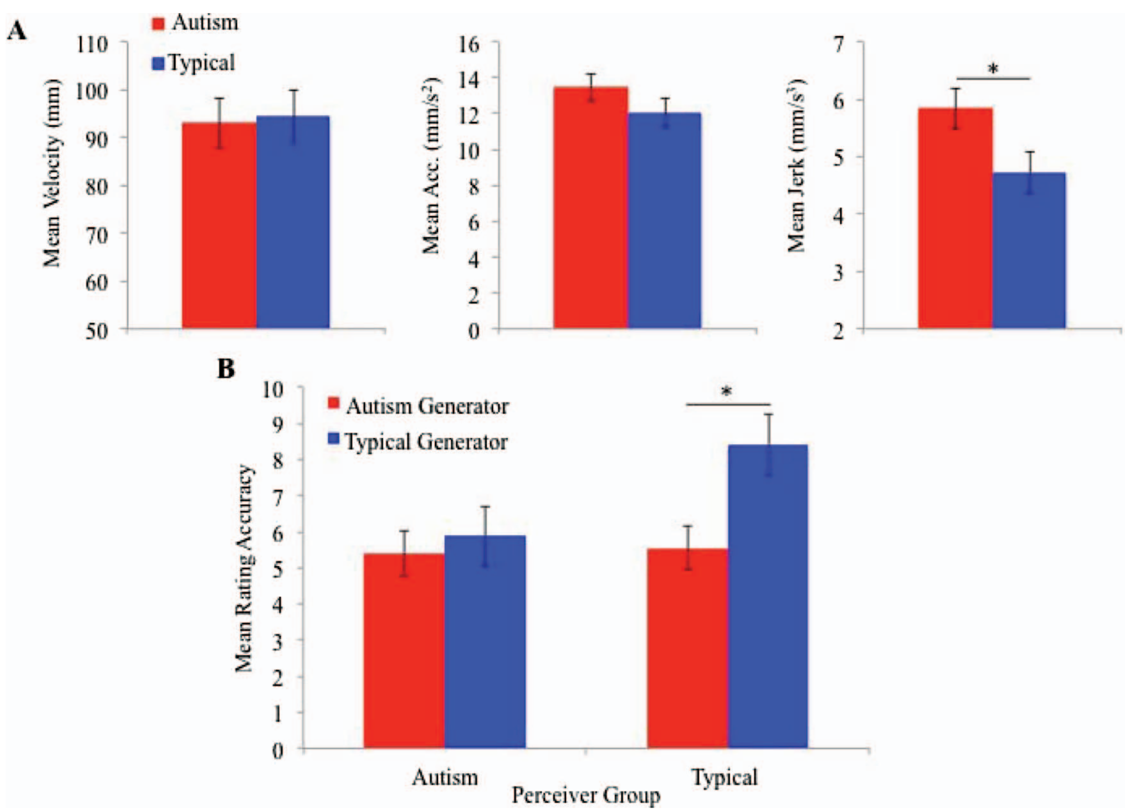

Figure 2. (A) Mean velocity, acceleration and jerk for the autism and typical animations. (B) Mean rating accuracy for the autism and typical groups when rating the autism and typical generated animations. Error bars represent the standard error of the mean. See the online article for the color version of this figure.

For each trial, participants' ratings were scored for accuracy. Accuracy was calculated by averaging the rating scores of the three "incorrect" scales (e.g., the mean rating of mocking, seducing, and surprising when viewing a coaxing animation), and subtracting this number from the "correct" scale rating. A score above 0 therefore indicates that the participants rated the intended mental state verb more highly than the other verbs, with higher scores indicating a greater match to the intended representation.

Results

The analyses below are reported collapsed across the four mental states (coaxing, mocking, seducing, surprising). Analyses including mental state as a within-participants factor are reported in the Supplementary Results.

Generated Animation Kinematic Analysis

To verify that the animations generated by the two groups differed in their kinematics, an independent-sample t test compared each kinematic measure extracted (jerk, acceleration, and velocity) between the two generator groups (autism or typical; see Figure 2A). Despite no difference in acceleration, $t(29) = 1.27$, $p = .213$, 95% CI [−.85, 3.69], $d = .46$, or velocity values, $t(29) = .17$, $p = .870$, 95% CI [−16.82, 14.30], $d = .06$, there was a difference with respect to jerk, $t(29) = 2.21$, $p = .035$, 95% CI [.08, 2.17], $d = .79$. Figure 2A demonstrates that this main effect was driven by increased jerk in the videos produced by individuals with autism, relative to the typical adults, thus replicating our previous demonstration of increased jerk in movements produced by individuals with autism (Cook et al., 2013).

Perceptual Task

The perceptual task data were analyzed using a mixed 2 × 2 ANOVA with perceiver group (autism or typical observers) as a between-participants factor, and generator group (autism or typical generator) as a within-participants factor.

The main effect of perceiver group was not significant, $F(1, 44) = 2.10$, $p = .155$, 95% CI [−.53, 3.24], $\eta^2 = .045$. There was a main effect of generator group with better rating accuracy when participants observed the typical (M = 7.14, SEM [standard error of the mean] = .61) compared to the autism animations (M = 5.45, SEM = .48; $F(1, 44) = 8.15$, $p = .007$, 95% CI [.49, 2.84], $\eta^2 = .156$). Most importantly, this effect was qualified by an interaction with perceiver group, $F(1, 44) = 4.14$, $p = .048$, $\eta^2 = .086$. Simple effects analysis showed the typical perceivers were significantly better at rating the typical animations than the autism animations ($p = .001$, 95% CI [1.23, 4.48], $d = .66$), but the autism perceivers performed equally for the autism and typical animations ($p = .563$, 95% CI [−1.22, 2.18], $d = .14$; Figure 2B).

Discussion

The present experiment required individuals with autism and matched typical adults to generate animations depicting mental states. The animations generated by the movements of the participants with autism were found to have greater jerk than their typical counterparts. In a subsequent perceptual task, the typical participants demonstrated an enhanced ability to attribute the intended mental state to the animations produced by other typical participants, relative to those produced by participants with autism. In contrast, individuals with autism exhibited no difference in assigning the intended mental state to animations produced by autistic and typical individuals.

Differences in movement kinematics between the groups replicate previous findings of increased jerk when adults with autism make simple horizontal arm movements (Cook et al., 2013). The current findings extend this work by showing that these atypical kinematics are evident when those with autism produce complex, object-based actions. A lack of typical kinematics might be a consequence of peripheral factors, such as abnormal muscle tone (Maurer & Damasio, 1982), or central nervous system factors, such as poor anticipation of the subsequent part of a motor sequence (Cattaneo et al., 2007). Interestingly, Cook et al. (2013) also found group differences in velocity and acceleration that were dependent upon the phase of the movement (turning point or midpoint; see also Forti et al., 2011; Glazebrook, Elliott, & Lyons, 2006). The phase effects are likely greater for larger magnitude movements (e.g., full length arm movements), therefore their absence in the present study may be due to the relatively small magnitude of movements (hand and wrist gestures).

Enhanced perception of typical, relative to autistic, actions in the typical perceiver group is consistent with previous work that suggests we interpret others' actions according to models built through experience with our own actions (e.g., Sebanz & Shiffrar, 2009). Typical adults are better at predicting movement outcomes that comply with typical kinematic trajectories (Kandel, Orliaguet, & Viviani, 2000), and those with more experience of performing a particular action are better able to predict the outcome of that action when it is observed (Diersch, Cross, Stadler, Schütz-Bosbach, & Rieger, 2012). The present study adds to these findings by showing that we are better at making higher-level mental state inferences (e.g., coaxing) from actions that look like our own.[2] Future work could compare the extent to which movement kinematics determine our ability to make lower- and higher-level inferences from observed actions, perhaps contrasting these animations against representations of simpler animate concepts (e.g., following).

Our findings have important implications for interaction difficulties between autistic and nonautistic individuals. Successful and fluid interactions depend on accurate anticipation and prediction of others' movements, allowing us to attribute affective states, intentions, and goals to our interaction partner so that we can adjust our behavior accordingly (Behrends, Müller, & Dziobek, 2012). Therefore, if typical action models are not effective for interpreting the movements of individuals with autism, then the "social impairments" exhibited by individuals with autism may, at least in part, be a product of a failure by typical individuals to infer correctly the affective states, desires, and intentions of autistic individuals. Inappropriate and/or inconsistent feedback from inter-

[2] It is important to note that all mental state information must have been derived from movement kinematics in the current study because there were no facial expressions, postures, or language in the animations. However, despite the fact that jerk is an important cue concerning mental states (e.g., Pollick, Paterson, Bruderlin, & Sanford, 2001), other kinematic cues (such as the correlation between the movements) may also have contributed to inferences.

action partners in response to misunderstood actions may also obstruct learning about typical social interaction in those with autism, interfering further with social and communication skill development. Crucially, incorrect interpretation of the movements of individuals with autism by typical individuals could also have important implications for clinical diagnosis. Autism is diagnosed following observation-based behavioral assessments of social functioning by a qualified clinician. On the basis of the current findings we might predict that social expressions by individuals with autism are harder to decode. Therefore, these individuals may be assessed as lacking social understanding or expression by nonautistic clinicians, whereas in reality they simply have models incompatible with those of the assessor. Similarly, other assessments that evaluate an individuals' internal states may fail to do so correctly when performed with autistic individuals, affecting sentencing, medical support, and treatments. Further study of how typical individuals could learn to interpret atypical expressions could improve intervention strategies and also reduce frustration, social anxiety, and mood problems in individuals with autism (Simonoff et al., 2012), who may express their internal states but be frequently misunderstood.

Despite performing the task at a reasonable level, with comparable performance to the typical group when observing "other" group animations, the autism group did not show the same benefit from observing "same" group animations—performance when observing autistic animations was comparable in the two observer groups. One potential explanation for the lack of "same" group benefit relates to the trend toward increased variability in the kinematics of the autistic relative to typical generators. For example, there was a trend for the four animation-specific jerk values to differ more in each individual in the autism group (between-groups t test on the standard deviations of the four jerk values; $t(29) = 1.94$, $p = .062$). Increased variability in autistic actions may mean that a given autistic participant's action models are a poorer fit to those of other autistic individuals (note that autistic facial expressions have also been shown to have more idiosyncratic qualities, which may similarly impair expression understanding; Brewer et al., 2016; Macdonald et al., 1989). Alternatively, autistic action models may be tuned to both atypical (autistic) and typical movements. Throughout their lives most individuals with autism have much experience observing and interacting with typical others, who move typically, as well as experience with their own atypical movements. In contrast, typical individuals are likely to have experience of typical movements only. These hypotheses could be elucidated by studying perception of autistic movements in individuals without autism but who have increased experience with this group.

The present findings have important implications for other clinical disorders that present with motor abnormalities. For example, other clinical populations characterized by developmental (e.g., Tourette Syndrome or cerebral palsy) or neurodegenerative (e.g., Huntington's Disease or cerebellar ataxia) motor atypicalities also show atypical intention attribution (Caillies, Hody, & Calmus, 2012; Eddy & Cavanna, 2015; Eddy & Rickards, 2015; Garrard, Martin, Giunti, & Cipolotti, 2008). Furthermore, our results may help to explain why children with Attention Deficit Hyperactivity Disorder (ADHD) and motor dysfunctions are rated as having more social interaction difficulties than children with ADHD only (Tervo, Azuma, Fogas, & Fiechtner, 2002). Intentions and emotions expressed by these children with ADHD may be misunderstood by typical peers, possibly resulting in increased frustration and inadequate social interactions (Nijmeijer et al., 2008). Even children and adults with motor dysfunction, without any clinical diagnosis, are more likely to experience less favorable social interactions (Bejerot & Humble, 2013). Our findings are therefore likely to apply to a number of conditions characterized by atypical movements, and suggest that interaction difficulties between typical and atypical individuals may not be attributable solely to the individual who has received a clinical diagnosis.

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Received April 5, 2016
Revision received July 25, 2016
Accepted July 25, 2016 ■