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Individual differences in high-level biological motion tasks correlate with autistic traits

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ABSTRACT

Human actions are rich in social cues and play an essential role in interacting with the social environment. Hence, the perception of biological motion (i.e., movement elicited by humans and other animals) is considered to be an important gauge of a person's social cognition capacities. It has been well-documented that Autism Spectrum Disorder (ASD) is associated with difficulties in social interactions. In the present study, we examined whether individual differences in biological motion perception relate to the degree of autistic traits among people in the typically-developing population. We employed three tasks that require different degrees of involvement of global action processing: action discrimination in noise, action inversion effect in binocular rivalry, and inter-personal interaction recognition. We found that individuals with higher numbers of autistic traits showed similar action discrimination performance as individuals with fewer autistic traits but exhibited a reduced inversion effect in binocular rivalry, and a decreased ability to recognize meaningful human interactions. These findings provide converging evidence that global processing of biological motion is affected in people with a high degree of autistic traits.

1. Introduction

In our very social world, a person who is not able to interact properly with other people, or correctly interprets their intentions, is confronted with a social disadvantage. Autism Spectrum Disorder (ASD) is a range of developmental conditions in which a person has difficulties with social interaction and social communication, and exhibits a restricted range of behaviors and interests (Frith, 1989). Because of the difficulties in these important social tasks, ASD has been the topic of many investigations.

Biological motion stimuli are very rich in social cues. Even very impoverished visual stimuli, consisting only of around a dozen points depicting joint movements of human body motion (point-light displays, PLD; (Johansson, 1973)) carry information about action types, emotions, gender, sign-language, and interactions (Chouchourelou, Matsuka, Harber, & Shiffrar, 2006; Dittrich, 1993; Dittrich, Troscianko, Lea, & Morgan, 1996; Manera, Del Giudice, Bara, Verfaillie, & Becchio, 2011; O'Toole et al., 2011; Poizner, Bellugi, & Lutes-Driscoll, 1981; Roether, Omlor, Christensen, & Giese, 2009; Thurman & Lu, 2014; van Boxtel & Lu, 2011, 2012). Because of the importance of biological motion perception in facilitating social communications, it has often been investigated in the clinical ASD population, as well as in the broader spectrum.

Early investigations showed that biological motion perception was impaired in the ASD population (Blake, Turner, Smoski, Pozdol, & Stone, 2003; Moore, Hobson, & Lee, 1997). Subsequent work has yielded mixed evidence regarding the impact of autism on biological motion perception (Kaiser & Pelphrey, 2012; Kaiser & Shiffrar, 2009). Some studies showed impairments in biological motion perception in ASD (Annaz et al., 2010; Klin, Lin, Gorrindo, Ramsay, & Jones, 2009; Koldewyn, Whitney, & Rivera, 2010; Nackaerts et al., 2012; van Boxtel, Dapretto, & Lu, 2016), but others found an absence of behavioral impairments (Cleary, Looney, Brady, & Fitzgerald, 2014; Cusack, Williams, & Neri, 2015; Herrington et al., 2007; Jones et al., 2011; Kaiser et al., 2010; McKay et al., 2012; Murphy, Brady, Fitzgerald, & Troje, 2009; Saygin, Cook, & Blakemore, 2010). Furthermore, some recent studies found that even in the absence of behavioral impairments, brain activity can still differ between the people with ASD and a control group (Freitag et al., 2008; Herrington et al., 2007; Kaiser et al., 2010; McKay et al., 2012), suggesting that more subtle differences in the neural mechanisms involved in biological motion processing

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may be present, even when not directly reflected in behavioral differences.

A possible contributor to the equivocal nature of the findings regarding biological motion perception in ASD is that many of the previously employed tasks can be solved using different processing levels. Biological motion perception is supported by both local processes that analyze motion trajectories of individual joints (e.g., foot movements in a walking action), and global processes that are sensitive to the combined movements of the joints resulting in posture changes over time (Chang & Troje, 2009a, 2009b; Hirai, Chang, Saunders, & Troje, 2011; Saunders, Suchan, & Troje, 2009; Thurman & Lu, 2013; Troje & Westhoff, 2006; van Boxtel & Lu, 2015). Many tasks, such as a discrimination task in which participants were asked to categorize a point-light walker embedded in a noise background (e.g., Jones et al., 2011; Koldewyn, Whitney, & Rivera, 2011; Koldewyn et al., 2010), could potentially be performed using *either* local movements of individual joints or global cues of body movements. Thus, if people in the general population process biological motions automatically at the global level, while people with ASD employ a more local process, a group difference would not be observed in behavioral measures. It follows that finding an impairment in the ASD group will depend not only on the type of stimulus (e.g., biological motion), but also on specific stimulus differences (e.g., type of noise, or type of action), or task differences (e.g., action detection/discrimination versus emotion detection/discrimination). Hence, to understand the impact of autism on biological motion perception, a range of experimental paradigms should be tested and compared.

In order to examine whether the perceptual difficulties in ASD extend into the general population, the present paper focuses on the relationship between individual differences in biological motion perception and variations in the degree of autistic traits among participants drawn from the typically-developing population. The systematic study of individual differences is a powerful paradigm that may reveal important findings that would otherwise be lost through averaging over individual results (Wilmer, 2008; Peterzell, 2016). Previous research has shown that people who are not clinically diagnosed with ASD also differ in their ability to interpret social actions and interactions, with some individuals being better than others. This variability in non-clinical samples has spurred interest in the "broader phenotype" of autism (Bailey et al., 1995). For example, researchers have tested family members of those diagnosed with ASD (e.g., Ahmed & Vander Wyk, 2013; Kaiser et al., 2010; Scheeren & Stauder, 2008), or looked at variation within the general population as a whole (see below).

The desire to investigate individual differences in ASD-related difficulties within the general population has inspired the development of a self-administered questionnaire that measures the number of "autistic traits" in adults (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) and children (Auyeung, Baron-Cohen, Wheelwright, & Allison, 2008). This questionnaire aims to measure "where any given individual lies on the continuum" in a quick and easy manner. The questionnaire yields a score of 0–50, which is termed the Autism-Spectrum Quotient (AQ), with higher scores meaning more autistic traits. The AQ score has been widely used in research settings to investigate individual differences, addressing a wide range of research questions, spanning from magnocellular visual responses (Sutherland & Crewther, 2010) to social understanding (Yang & Baillargeon, 2013). One of the main aims has been to investigate the relation between social perception tasks and the AQ. In the present paper, we will focus on the task of biological motion perception, which is considered to be an important gauge of a person's social cognition capacities (Pavlova, 2012).

The relation between individual differences in biological motion perception and the degree of autistic traits has recently received attention in several studies. Miller and Saygin (2013) found that an individual's ability to perform tasks that involve form cues in biological motion correlated with measures of social perception, including Empathy Quotient (EQ), AQ and Reading the Mind in the Eyes Test (RMET). Our recent study also showed that individuals with a high number of autistic traits display reduced adaptation to biological motion at the global processing level (van Boxtel & Lu, 2013b) (as was subsequently confirmed in an ASD sample; van Boxtel et al., 2016). Individuals with high AQ scores are distracted to a lesser extent by task-irrelevant biological motion (van Boxtel & Lu, 2013b). People with a high level of autistic traits have also been found to have an elevated detection threshold for biological motion stimuli, and this effect was especially strong for threatening actions (Kaiser & Shiffrar, 2012). This latter finding is consistent with a reduced recognition of fear in biological motion displays by people with high levels of autistic traits (Actis-Grosso, Bossi, & Ricciardelli, 2015).

To examine the relation between biological motion perception and autistic traits more systematically, we gathered data on three biological motion tasks, aiming to vary the degree to which global processing is needed to perform the tasks in the different experiments. We focused on action discrimination in noise in Experiment 1, inversion effects during binocular rivalry in Experiment 2, and recognition of inter-personal interactivity in Experiment 3. We aimed to investigate tasks that could potentially be solved based on local processing alone (discrimination in noise), tasks that require automatic holistic processing, and tasks that heavily rely on global processing (such as recognition of meaningful interactivity between two actors). This range of tasks allowed us to examine the dependence of AQ on different levels of action processing.

2. Experiment 1: Biological motion discrimination in noise does not correlate with AQ

Previous research found that individuals with autism showed reduced discrimination to biological motion in noise relative to a control group (Annaz et al., 2010; Koldewyn et al., 2010, 2011). In Experiment 1, we employed the classic paradigm of dynamic random dot kinematograms to mask action dynamics, and to measure action discriminability. We measured the discrimination of facing directions of walking actors, and investigated the relationship between discrimination performance and the AQ measure in the typically-developing population.

2.1. Participants

Seventy-two undergraduate students at the University of California, Los Angeles (UCLA) (mean age = 20.6 years; 46 female) participated in the experiment for course credit. All participants involved in the three studies reported in the present paper had normal or corrected-to-normal vision. Throughout the paper we excluded potential outliers based on Z-scores of both the dependent measure and the AQ score, excluding participants that were more extreme than 99% of the population (abs(Z) > 2.5758). We excluded one participant based on this exclusion criterion in the analysis of Experiment 1.

2.2. Stimuli

All action stimuli in the present paper were selected from the CMU motion-capture database (http://mocap.cs.cmu.edu) and processed by the Biological Motion Toolbox (van Boxtel & Lu, 2013a). In Experiment 1, we selected one walker from the dataset and presented the walking action with the point-light display (Johansson, 1973) in the profile view, as shown in Fig. 1 (left). The point-light

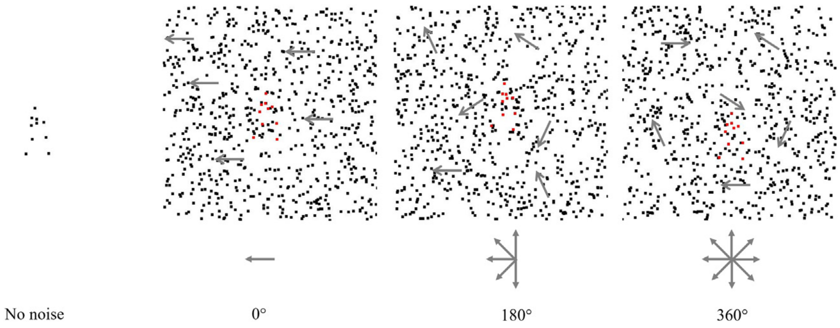

Fig. 1. Illustrations of stimuli in Experiment 1. The point-light walker was embedded in noise dots. The noise dots move in directions sampled from different ranges of moving directions. From left to right, the figure presents a trial with no noise, 0°, 180° and 360° of noise background. The arrows indicate example moving directions of the noise dots and were not presented during the experiment.

walker was comprised of 10 dots placed on the major joints: one shoulder joint, one hip joint, two elbow joints, two hands, two knees and two feet. Dots were displayed continuously without resampling. The horizontal translation of the walking action was removed so that the actor appeared to walk on a treadmill. Stimuli were presented on a 17-inch screen with the resolution of 1024 × 768 pixels and 60 Hz refresh rate. Participants used a chinrest to maintain a fixed viewing distance of 35 cm.

Stimuli were presented in a square window (12° by 12° of visual angle) centered on the screen, and were displayed in black (0 cd/m^2) on a white background (145.5 cd/m^2). The size of the walker was a maximum of 2.5° in width by 5° in height. On each trial the walker was presented at a location randomly selected within the range of 1/6th window width relative to the center of the display window. To measure the thresholds for biological motion discrimination, the point-light walker was embedded in dynamic random dot kinematograms. In the random dot kinematogram, dots were randomly scattered over the screen with a dot density of 5 dots/degree^2. Each dot was independently assigned with a moving direction sampled from a uniform distribution with a certain angular range (Williams & Sekuler, 1984). The range of the distribution of directions varied from 0° (i.e., all the noise dots move in a coherent direction) to 360° (i.e., noise dots move in random directions). As shown in Fig. 1, when all the noise dots moved in the same direction (left or right) for the direction range of 0, and the point-light walker can easily pop out from the noise dot background. When the distribution range of motion directions was 360°, noise dots moved in all directions and no coherent motion could be perceived. The speed of each dot was independently sampled from a range from 1.43 degree/s to 4.29 degree/s, and each dot was also assigned a lifetime that varied between 33.3 ms and 166.67 ms. The speed and moving direction of the dot remained the same during its lifetime. Replaced dots were assigned with a new speed, moving direction and lifetime. The average moving direction of the random dot kinematrogram was randomly selected on each trial. Each trial lasted for 1.67 s.

Participants were asked to report which direction the point-light actor was walking (left or right) by pressing the left arrow or right arrow on the keyboard. Responses could be made at any time after the onset of the stimuli.

2.3. Procedure

First, participants were presented with 14 practice trials with gradually increasing task difficulty. The first 5 trials were presented without noise dots to familiarize subjects with the task of walking direction judgment. In the next 4 trials, noise dots were presented with a range of directions of 0°. In the final 5 practice trials, moving directions of noise were randomly select in a range of [−100°, 100°].

In the experimental block, we employed the Palamedes module (Prins & Kingdom, 2009) to carry out Bayesian adaptive "Psi" staircase method (Kontsevich & Tyler, 1999) to assign the direction range for each trial. The Psi-staircase assumed a log-Weibull (Gumbel) function with a non-zero (2%) attentional lapse rate (Lambda) and a 5% guess rate (Gamma). In each block, two randomly interleaved Psi-staircases were employed with 35 trials per staircase, and each determined the threshold (i.e., the range of directions of noise) to yield a 75% accuracy of discrimination performance for determining walking direction. The two threshold estimates were averaged to produce the dependent measure for each subject.

At the end of the experiment, participants completed the Autism-spectrum Quotient (AQ) questionnaire developed by Baron-Cohen et al. (2001), where AQ scores provided a measure of the degree of autistic traits.

All experiments in this paper were reviewed and approved by the UCLA review board and were performed in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Informed consent was obtained from all participants.

2.4. Results

Participants were able to discriminate the walking direction of a point-light walker embedded in a considerable amount of noise. Participants reached 75% discrimination accuracy when the target walker was embedded in the noise dots with random motion directions sampled from an average direction range of 203 degrees ($SD = 47.8$) (see Fig. 2). We examined the correlation between the discrimination threshold of biological motion perception and the AQ measure of autistic traits. We checked for normality (Shapiro-Wilk test) of AQ scores and discrimination thresholds. AQ did not differ significantly from normality, but the threshold did ($p = 0.015$). The fitting results indicated that both measures did not show a significant amount of heteroscedasticity. We first conducted a regression on the raw threshold data. As shown in Fig. 2, the correlation between discrimination thresholds and AQ scores was not significant $r = 0.049$, confidence interval (CI) = [−0.19, 0.29], $p = 0.69$, indicating a lack of relation between the ability to discriminate walking direction and the degree of autistic traits. To examine whether these results were due to the non-normality of the threshold measure, we transformed the data with the function sign(th) * abs(th)^(0.8), where *th* stands for the individual threshold measures minus the overall median threshold. This transformation removed the leptokurtic shape of the distribution, but the subsequent regression analysis remained non-significant ($r = 0.059$, CI = [−0.18, 0.23], $p = 0.63$).

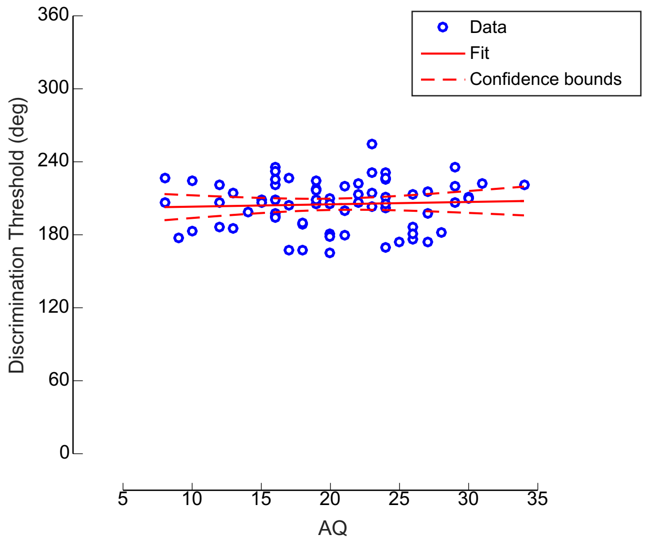

Fig. 2. Results of Experiment 1, showing the lack of relation between AQ scores and the threshold of biological motion discrimination. Some data point overlap.

3. Experiment 2: Bias for upright actions during binocular rivalry correlates with AQ

Humans appear to process both faces and biological motion in a holistic manner, as evidenced by superior task performance for upright as compared to inverted stimuli. However, studies have revealed that this effect is diminished (or absent) in people with ASD or high AQ scores for both faces and biological motion (e.g., Cleary et al., 2014; Cusack et al., 2015; O'Brien, Spencer, Girges, Johnston, & Hill, 2014; Wyer, Martin, Pickup, & Macrae, 2012).

Here we took a novel approach to address this question, and investigated which orientation the visual system prefers (upright or inverted), when both are presented in visual conflict with each other. We showed an upright actor in one eye, and an inverted actor in the other eye. Both actors occupied the same location, thus inducing binocular rivalry (Alais & Blake, 2005). If there is an inherent bias toward processing upright actions, the upright actions should gain visual dominance over the inverted action for a longer time period. The present experiment aimed to examine whether this difference decreases for individuals with more autistic traits.

3.1. Participants

Seventy-nine UCLA undergraduate students (mean age 20.6 years, 58 female) participated in Experiment 2. We employed a similar design to that used in our early study (Su, van Boxtel, & Lu, 2016), and predominance results from the first 16 participants were reported in that paper (the AQ data were not analyzed previously). We applied the same Z-score criterion as in Experiment 1 to identify potential outliers, resulting in 3 participants being excluded. A final sample of 76 participants was included in the analysis.

3.2. Stimuli

Stimuli were displayed on a calibrated Viewsonic CRT monitor with a resolution of 1280 × 1024 pixels, and were created using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Participants viewed the stimuli through an adjustable stereoscope from Berezin Stereo Photography Products at a constant viewing distance of 57 cm maintained by a chin rest.

On each trial, we showed two rival point-light female salsa dancers for 26 s, one to each eye and in different colors (blue and red) to induce binocular rivalry. Rival stimuli were shown with luminance level of 10.6 cd/m^2 for the two colors on a black background ($\sim$0 cd/m^2). Actors subtended 7.3 by 5.3 degrees of visual angle. The size of each point-light was 0.13°. A central fixation cross (with size of 0.75° by 0.75°) was presented, as well as a frame surrounding the stimuli on the screen to help subjects register the same position in the two eyes. The extrinsic body movements were removed from the stimuli to show actions in place.

Previous research (Blake, 1989; Blake, Yu, Lokey, & Norman, 1998) has shown that speeds of about 1.2 deg/s strongly attract dominance in rivalry, yielding exclusive visibility of one eye's view (Blake, 1977). To prevent the speeds of smoothly moving joints to determine the rivalry dynamics, locations of point-lights were randomly sampled along the limbs in each frame, that is, with a limited lifetime of one frame (i.e., 13 ms) (Beintema & Lappe, 2002). Each actor was composed of nine dots (the head, and eight dots randomly sampled on each of the 8 limb segments).

3.3. Procedure

Participates completed a practice session using the walking rival stimuli (Watson, Pearson, & Clifford, 2004). The practice session included (in intermixed order) four trials showing two upright walkers with different facing directions (leftward or rightward) presented one to each eye, in different colors (red or blue), and four additional trials showing inverted walkers as the rival stimuli.

In the subsequent test session, dichoptic stimuli were presented: an upright dancer to one eye and an inverted dancer to the other eye, each in a different color. Each actor was presented with limited lifetime point-lights (as shown in Fig. 3 left panel). The locations of the point-lights along the skeleton for the two rival actors were independently sampled. The experiment consisted of 32 trials. Participants were asked to indicate the color of the dominant actor (red, blue or mixed), by pressing and holding one of three keys to indicate whether the "blue" (left arrow) or "red" (right arrow) dots were more visible, or the two groups of colored dots were equally visible (down arrow), at any moment throughout the trial. The upright and inverted actors as well as the colors were counterbalanced between the eyes over trials. The dependent measures were predominance levels. These were calculated as the total dominance time of a rival stimulus (as determined by the duration of button presses for its corresponding color in the rivalry), divided by the trial duration. This was done separately for both upright and inverted actors. At the end of all trial presentation, participants completed the Autism-Spectrum Quotient (AQ) questionnaire.

3.4. Results

The predominance (the summed proportion of reported dominance of rival actions during the viewing period) for upright dancers ($M = 36.53\%$) was significantly greater than that of the inverted dancers ($M = 24.47\%$; $t(75) = 7.61$, $p < 0.0001$, Cohen's $d = 0.87$). These results replicate our previous finding (Su et al., 2016). This finding indicates that when upright and inverted actions directly compete with each other in a rivalry setup, the visual system is biased toward the more ecologically-relevant upright orientation upright action. Because we use the limited-lifetime technique, contribution of local motion mechanisms such as a "life-detector" based on characteristic movements of the feet for walking (Troje & Westhoff, 2006; van Boxtel & Lu, 2015) are relatively minimal. Hence, the present paradigm allows us to identify rivalry effects primarily attributable to global action perception.

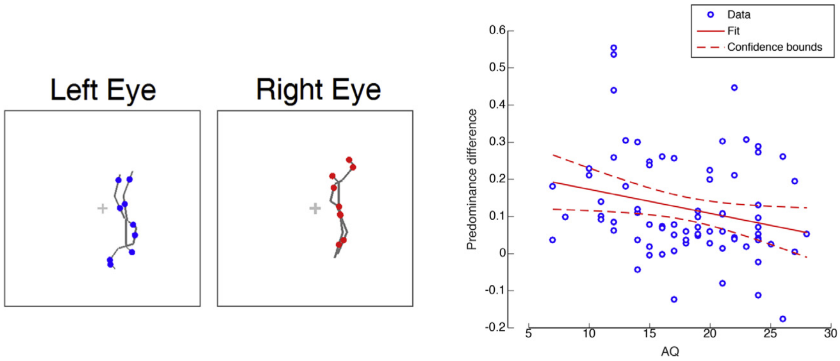

Fig. 3. Stimulus illustration and results for Experiment 2. Left: Schematic illustration of rival dance actions in different colors in dichoptic presentation. One eye viewed an upright dancer and the other eye viewed an inverted dancer. The gray lines are only for illustration purpose to show the randomly sampled dots along the limbs, and were not shown in the experiment. Right: scatter plot showing correlation between predominance difference (the summed proportion of reported dominance of the upright action minus the proportion for the inverted action) and AQ score, with 95% confidence bounds.

More interestingly, the priority received by ecological orientation of upright body was measured as predominance difference, the summed proportion of reported dominance of the upright action minus the proportion for the inverted action. We found that predominance difference was significantly correlated with participants' AQ scores $r = -0.24$, $\text{CI} = [-0.47, -0.018]$, $p = 0.034$. The dependence measure did neither show significant deviation from normality, nor significant heteroscedasticity according to White test. As shown in Fig. 3 right panel, individuals with more autistic traits showed less predominance of the upright actions in comparison to the inverted actions, perhaps because those individuals have a decreased perceptual grouping in the upright actor (Tadin, Lappin, Blake, & Grossman, 2002).

4. Experiment 3: Interactivity judgment correlates with AQ

People with ASD have difficulties with social interactions and social communication in daily life. A previous investigation of interaction perception showed no decrease in performance in an ASD group relative to a control group (Cusack et al., 2015). However, this study only used two types of interactions (boxing and dancing), which may have reduced task difficulty. Furthermore, the degree of interaction was manipulated by shifting the action sequence of one agent forward or backward in time, which may be relative easy to distinguish from correctly-timed interactions, thus decreasing the likelihood of discovering a group difference. In the present experiment, we selected a large number of paired actions in order to examine whether the ability to identify meaningful interactions between two people correlates with AQ scores.

4.1. Participants

Ninety-nine UCLA undergraduate students (mean age = 20.6 years; 66 female) participated in the experiment for course credit. All participants had normal or corrected-to-normal vision. Ten out of 99 participants were excluded from the data analysis due to the following reasons. Three participants were excluded because they failed one of the attention checks in the rating task or in the AQ questionnaire (see procedure). Six participants were excluded because they provided the same ratings for almost all the trials, including both interactive and non-interactive trials. One additional participant was excluded based on the z-score analysis.

4.2. Stimuli

Experiment 3 employed ten interactive actions, each involving two human agents who were engaged in various forms of meaningful social interactions (including shake hands, pull by arm, high five, give drink, arm wrest, argue, play 360 whip, salsa dance, one person moved an object in a way to threaten the other person, and play catch). Actions were presented as black stick figures with line segments (6 pix wide) connecting the joints according to human body structure, together with dots of 6.37 pix diameter on the joints, and a 12.73 pix diameter dot for the head. The background was white. All action videos lasted 3.67 s. Experiment 3 employed a total of 100 stimuli with paired actions, consisting of all pairwise combinations of the two actors in the 10 interactions. Therefore, the stimulus set included 10 interactive stimuli showing partnered actors in the truly interactive inter-personal interactions, and 90 non-interactive stimuli consisting of two actors each sampled from two different interactions in the stimulus set (e.g., one agent from shake-hands action and the other from high-five action). Fig. 4 (left) depicts two examples of stimuli used in the experiment.

4.3. Procedure

Participants first viewed two practice trials each including two single-actor actions, walking and running, presented in the stick-figure format, to familiarize them with the display format. Participants were asked to describe what actions they perceived in these two practice trials. They then viewed 100 paired action sequences in a random order. On each trial participants were asked to "rate the degree to which the actors appear to be interacting" on a scale from −3 (Definitely NOT) to 3 (Definitely) after viewing the two-actor display.

The experiment included two filler trials, consisting of a single actor walking or running. Participants were asked to use a slider (as in the rating scale for experimental trials) to choose the action depicted in each video. The two filler trials were presented at randomly selected places in the experiment to check whether participants paid attend to the task

After the rating task, participants completed the Autism Quotient (AQ) questionnaire. In this experiment, an attention-check question was included at a random place in the questionnaire, in which participants were asked to check a specified item. A similar design was used in an online experiment with a between-subject design that was reported in our previous paper (Shu, Thurman, Chen, Zhu, & Lu, 2016).

4.4. Results

As shown in Fig. 4 (right), participants provided significantly higher average ratings for interactive pairs ($M = 2.42$, $SD = 0.36$) than for non-interactive pairs ($M = -0.68$, $SD = 0.75$), $t(88)$

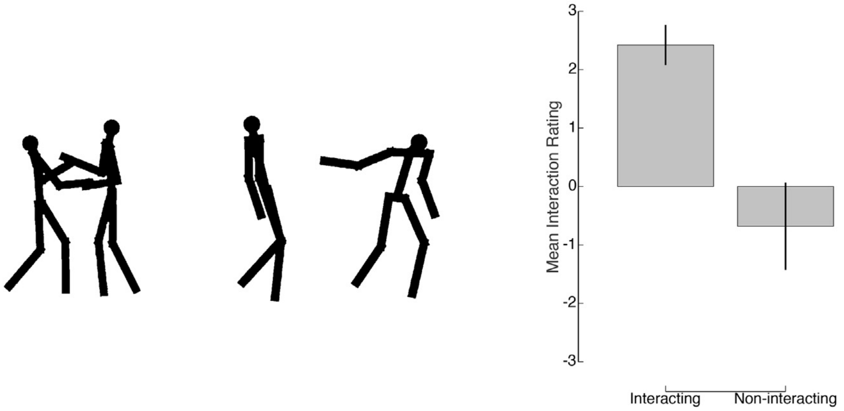

Fig. 4. Stimulus illustration and results for Experiment 3. Left, illustration of stimuli in an interactive trial (left) and in a non-interactive trial (right). Right, mean (±SD) interactivity ratings for truly interacting and non-interacting stimuli, computed by collapsing across action types.

= 34.90, $p < 0.001$ (CI of the difference: [2.93, 3.28]), demonstrating that participants were able to discriminate truly interpersonal interactions from action pairs in the absence of interactivity.

To explore the role of individual differences in judging interactivity between actions, we examined the relationship between AQ score and ability to identify inter-personal interactions. Interaction Ratings, discrimination scores and AQ measures did not differ significantly from normality (Shapiro-Wilk tests, $p > 0.05$). Homoscedasticity was not violated for the fit residuals (White tests, $p > 0.05$). As shown in Fig. 5 (left), we found a significant negative correlation between AQ score and interactivity ratings for truly interactive actions, $r(87) = -0.25$, CI = [−0.46, −0.045] $p = 0.018$; see Fig. 5 left panel). In addition, we calculated a discrimination score based on the difference between mean ratings for truly interactive pairs relative to mean ratings for non-interactive pairs. As shown in Fig. 5 (right), the correlation between AQ score and the difference score was also significant, $r(87) = -0.23$, CI = [−0.43, −0.019], $p = 0.033$. These negative correlation indices reveal that participants with more autistic traits were less able to identify interactivity between actors, and also less able to distinguish between interactive and non-interactive actions, relative to participants with fewer autistic traits.

5. General discussion

In the present paper we reported three different psychophysical experiments, each gauging different types of processing involved in biological motion perception. We found that people with more autistic traits showed decreased performance in some tasks (Experiments 2 and 3), whereas there was no such effect in another task (Experiment 1). These findings suggest that people with increased levels of autistic traits (and possibly by extension people with ASD) are not deficient in all biological motion perception tasks, but only in a subset of them (see Fig. 6 for a comparison of the different experiments). We propose that whether or not a deficit is evident likely depends on specific stimulus properties or task requirements that result in the involvement of different processes.

5.1. Biological motion discrimination in noise

In Experiment 1, we found that there was no correlation between walking direction discrimination thresholds and the degree of autistic traits. This finding is consistent with some other studies that have examined discrimination thresholds in the ASD population. For example, it has been found that people diagnosed with ASD do not show increased thresholds for biological motion detection in noise (Cusack et al., 2015; Jones et al., 2011), action discrimination in noise (Cusack et al., 2015), or walking direction

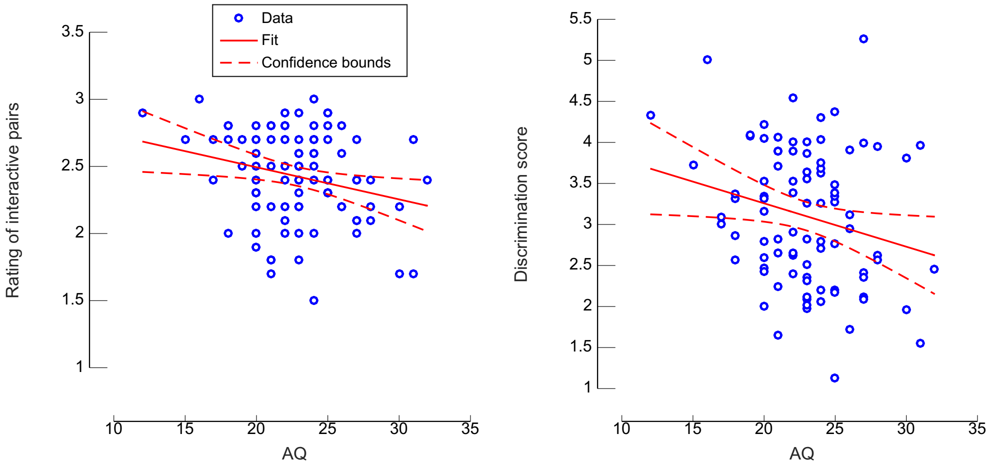

Fig. 5. Results of Experiment 3. Left, Scatter plot of AQ score and the average interactivity rating of true interaction stimuli. Right, Scatter plot of AQ score and discrimination score. Both plots yield negative correlations, indicating that with an increase in AQ score, the average ratings of truly interactive actions, and discrimination scores, both decrease. Some data points overlap.

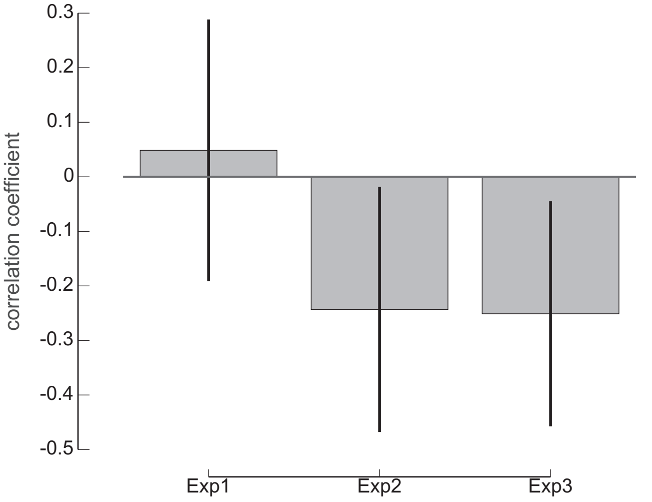

Fig. 6. Comparison across the three experiments. Correlation ±95% confidence intervals.

discrimination in noise (Murphy et al., 2009). However, other studies have shown group differences in a walking direction discrimination in noise task (Koldewyn et al., 2010, 2011), and detection in noise task (Annaz et al., 2010).

A recent study (Miller & Saygin, 2013) examined individual differences in typically-developing population in the recognition of walking actions. The study presented point-light walker that faced leftward or rightward on different trials, and moved forward or backwards. This design enabled the independent control of facing direction and walking direction that are often present in biological motion tasks. Importantly, the walking direction discrimination task relies on local mechanisms, comparing local motion trajectories of individual joints (e.g., foot moves along a clockwise trajectory for rightward walking), while the facing direction discrimination task requires spatial integration of multiple moving joints of the body posture (i.e., more rely on global processing). The authors found no correlation between the degrees of autistic traits and walking direction discrimination performance, but they did find a correlation between autistic traits and facing direction performance (Miller & Saygin, 2013), suggesting that the impact of autistic traits on a biological motion task when integration (i.e. global processing) is required. Another study in the typically-developing population found that the sensitivity of detecting a point-light walker in noise correlated the number of autistic traits (Kaiser & Shiffrar, 2012).

In interpreting this mixed set of results, one division that has been suggested (Jones et al., 2011) is that studies that employed action detection tasks are more likely to show a difference between ASD and control groups or between people with high and low degree of autistic traits, whereas studies that examined action discrimination ability do not show such a difference. Our results are consistent with this proposal, as we found no relationship between autistic traits and performance when performing an action discrimination task. This division could result from the fact that biological motion detection is influenced by contextual (i.e., global) information (Neri, Luu, & Levi, 2006), while walking direction discrimination could conceivably be done with either local or global processing.

5.2. Global processing and ASD

Previous research has shown that people with ASD employ a decreased amount of global processing relative to local processing in various perceptual tasks (Happé & Frith, 2006; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006), although the impact of autism on the involvement of different levels of processing depends on the task and stimulus (Van Eylen, Boets, Steyaert, Wagemans, & Noens, 2015). For example, people with ASD or high numbers of autistic traits show decreased inversion effects compared to a matched control group (e.g., Cleary et al., 2014; O'Brien et al., 2014; Wyer et al., 2012). In the present Experiment 2, we measured the inversion effect by assessing which action (upright or inverted) was granted access to visual awareness in a binocular rivalry paradigm. We found that people with increased levels of autistic traits show a reduced preference for upright actions in comparison with inverted actors, suggesting reduced involvement of global processing in gating stimuli.

Experiment 3 went beyond global processing of a single actor, investigating the perception of interactions between actors. Given the interpretive aspect of social perception in this task, one would expect people with ASD (or with a high AQ score) to perform less well in identifying interactive activities. We indeed found that people with higher levels of autistic traits were less able to differentiate between interactive and non-interactive actions.

A previous investigation into perception of human interaction showed no decrease in performance in an ASD group relative to a matched control group of typically-developing individuals (Cusack et al., 2015). However, this study only used two different interactions (boxing and dancing), which reduced task difficulty and may have led to a ceiling effect. We expanded the stimulus set to 10 interactive activities and created non-interactive actions by pairing agents from different interactions. This larger action set and new way of generating non-interactive stimuli increased task difficulty, and potentially made our paradigm more sensitive to individual differences in interaction perception.

Our results are also consistent with other research examining more "interpretative" aspects of biological motion perception that requires global processing of biological motion stimuli, such as emotion perception. For example, previous research has shown that people with ASD show impairments in discriminating and describing emotions portrayed with biological motion stimuli (Hubert et al., 2007; Nackaerts et al., 2012; Parron et al., 2008).

Our findings in Experiment 3 may not necessarily result from individual differences in perception. A potentially different cause of our findings is that people with higher levels of autistic traits interpreted the task differently, so that they had different criterion in judging what action stimuli were considered to be interactive. This would mean that people have different degrees of inclination or bias to consider observed actions as interactive in the social context. This is reminiscent of previous suggestions that people with ASD are not less able to process global information (which would suggest a perceptual difference), but are merely less inclined to process this type of information (Happé & Frith, 2006; Plaisted, Swettenham, & Rees, 1999).

6. Conclusions

Our work shows that, depending on the task, correlations may be present or absent between levels of autistic traits and performance in biological motion perception tasks. To account for this variability across three different experiments, we hypothesize that an important contributor is whether human participants can perform a task based on local motion cues only, or whether the task requires global cues as well. Our action discrimination task in Experiment 1 could potentially have been performed based on local motion cues only, thus not necessarily putting people with a higher level of autistic traits at a disadvantage. However, the tasks in Experiments 2 and 3 relied more on the global, holistic interpretations of the action stimuli, yielding a negative impact of high levels of autistic traits on performance (see Fig. 6, for a comparison). Thus, performance across a range of biological motion tasks varies from person to person. Some individual differences in biological motion perception are associated with the degree of autistic traits in the typical population. We note that what constitutes local or global processing is suggestive at the moment, because there are no strict definitions of either. Potential contributions of the differences between the results in our experiment could be due to the number of dots used, or the amount of signal vs noise dots, or perhaps the type of movement of the actors or the trajectories of the joints. Although each of these potential contributions may map onto some definition of global or local processing, due to the lack of generally agreed-upon definitions, it is not clear at the moment whether we can interpret these contributions (exclusively) as local or global information.

Nevertheless, in our data there does not appear to be a general disadvantage for people with higher levels of autistic traits in biological motion perception, per se. Rather, there may be a specific impairment only when task performance depends on global (contextual) processing.

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