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Preserved action recognition in children with autism spectrum disorders: Evidence from an EEG and eye-tracking study

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Abstract

Individuals with Autism Spectrum Disorder (ASD) have difficulties recognizing and understanding others' actions. The goal of the present study was to determine whether children with and without ASD show differences in the way they process stimuli depicting Biological Motion (BM). Thirty-two children aged 7–16 (16 ASD and 16 typically developing (TD) controls) participated in two experiments. In the first experiment, electroencephalography (EEG) was used to record low (8–10 Hz) and high (10–13 Hz) mu and beta (15–25 Hz) bands during the observation three different Point Light Displays (PLD) of action. In the second experiment, participants answered to action-recognition tests and their accuracy and response time were recorded, together with their eye-movements. There were no group differences in EEG data (first experiment), indicating that children with and without ASD do not differ in their mu suppression (8–13 Hz) and beta activity (15–25 Hz). However, behavioral data from second experiment revealed that children with ASD were less accurate and slower than TD children in their responses to an action recognition task. In addition, eye-tracking data indicated that children with ASD paid less attention to the body compared to the background when watching PLD stimuli. Our results indicate that the more the participants focused on the PLDs, the more they displayed mu suppressions. These results could challenge the results of previous studies that had not controlled for visual attention and found a possible deficit in MNS functions of individuals with ASD. We discuss possible mechanisms and interpretations.

KEYWORDS

alpha Wave, EEG, motor skills, perception, point-light displays

1 | INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized by difficulties in social and communication skills, as well as by the presence of restricted and repetitive behaviors (American Psychiatric Association, 2013). Although some individuals with ASD are delayed in their motor development (Arabameri & Sotoodeh, 2015), the presence of motor abnormalities is not a diagnostic criterion of ASD. Interacting with other people and interpreting their intentions correctly is an essential ability, as the world is social in nature. Whether the ability to perceive others' action is preserved or altered in autism remains unclear (Saygin et al., 2010). Difficulties in the production and perception of body movements and gestures as well as in motor imitation have been shown by previous studies in children with ASD (Ingersoll, 2008; Vanvuchelen et al., 2007). Ingersoll (2008) revealed that children with ASD have difficulty in imitating

model's actions. Also, children with ASD have less coordinated joint attention during imitation. Although facial expressions contain socially communicative information, other sources of information such as pure kinematic information (such as the one presented in Point Light Displays (PLDs)) have an important role when facial information is unavailable or inconsistent (Alaerts et al., 2017).

PLDs consist of a number of small lights attached to joint and other parts of the body of a model, with the body itself is not visible (American Psychological Association, 2016). Moving dots in PLDs elicit action perception in the observer (Johansson, 1973). The bodily movements portrayed by PLDs convey important social cues, as they can indicate others' emotions, gender, type of action, and interactions (van Boxtel et al., 2016). Studies investigating perception of PLDs in individuals with ASD at the behavioral and neural level have reported inconsistent results (Kaiser & Pelphrey, 2012; van Boxtel et al., 2016). These are reviewed below.

1.1 | Behavioral studies

Given that we tested solely children and adolescent in this study, we limit our review to previous relevant literature with participants in that age range. An early study investigating motion perception in autism (Moore et al., 1997) found that children and adolescents with ASD and age-matched controls with a learning disability were equally able to recognize objects based on their movements. Their results were also replicated by other studies (Cusack et al., 2015; Parron et al., 2008; Sotoodeh et al., 2019). For example, Cusack et al. (2015) conducted five studies and revealed that adolescent participants with ASD have intact PLDs perception. Wang et al. (2015) found that ASD children were less accurate and slower (but not completely incapable) than TD children in action recognition task. Recently Sotoodeh et al. (2019), revealed that children and adolescents with ASD showed same mirror neuron activation as Typically Developing (TD) participants, although slower, in perceiving BM.

Hubert et al. (2007), revealed that young individuals with autism and Asperger Syndrome (AS) were as able as controls to name PLDs of non-human objects and human movements. However, they were impaired at labeling the emotion displayed by PLDs, suggesting difficulties in processing emotional states. When comparing psychophysical thresholds of biological and non-biological motion perception in adults with ASD and TD control, participants with ASD were only impaired in the emotion determination condition (Saygin et al., 2010). However, other studies have revealed that adults with ASD are impaired in the action recognition when compared with typically developed adults (Hsiung et al., 2019; Nackaerts et al., 2012). Some factors may affect the results of previous studies and explain the inconsistency of their results: (1) different tasks (walking (Freitag et al., 2008; Moore et al., 1997; Murphy et al., 2009; Saygin et al., 2010), diverse action PLDs (Annaz et al., 2010; Blake et al., 2003; Hubert et al., 2007), spatially scrambled PLDs (Nackaerts et al., 2012), (2) different age range (children (Wang et al., 2015), adolescents (Cusack et al., 2015; Sotoodeh et al., 2019), young adults (Hubert et al., 2007) and adults (Hsiung et al., 2019; Saygin et al., 2010)), (3) different inclusion criteria for intelligence quotient (IQ>70 (Freitag et al., 2008; Murphy et al., 2009; Sotoodeh et al., 2019) versus IQ> 100 (Cusack et al., 2015; Saygin et al., 2010)) , (4) different levels of autism severity.

Although TD infants preferentially attend to the BM, individuals with ASD do less so, and Klin et al. (2009) reported that infants with ASD do not preferentially attend to BM. Based on their results, it is possible that perception of BM may be altered in children with ASD from a very early age. Annaz et al. (2012) showed that young children with ASD (3–7 years) did not preferentially attend to the BM of walking over phase-scrambled motion or to the PLD of a spinning top rather than to the PLD of a human walker. In contrast, TD children preferentially attended to human BM in both conditions. Using an eye-tracking system, Nackaerts et al. (2012) found that ASD participants produced more saccades and had shorter fixations when watching walking PLDs than their matched TD controls, in addition to being slower and less accurate at PLDs recognition. In line with these findings, a more recent study in children aged 3–7 showed that relative to TD children, those with ASD attended to PLDs less, and had shorter fixation to PLDs (Wang et al., 2015).

1.2 | Electrophysiological studies

The Mirror Neuron system (MNS) includes the parietal cortex and the inferior frontal cortex/ventral premotor cortex, and plays a role in the coupling between action observation and execution. The MNS is also involved in general social cognitive abilities such as perspective taking, action perception, theory of mind, and empathizing (Iacoboni & Dapretto, 2006; Rizzolatti & Craighero, 2004). Based on the broken MNS hypothesis of autism (Iacoboni & Dapretto, 2006; Oberman et al., 2005), an early deficit in the MNS function prevents children with ASD from developing an accurate perception of others' mind and results in inadequate sociocognitive skills. Several methods have been proposed to test the integrity of the MNS, including fMRI and EEG.

When recording EEG, frequencies in the mu (8–13 Hz) and beta (13–25 Hz) range are typically measured over central and parieto-central areas of the brain. Suppression of activity at these frequency ranges has been associated with a variety of movements, such as body movements, passive movements, command movements, reflexive movements, and tactile stimulation (Yin, Liu, & Ding, 2016). Motor

planning, imagery, and action perception can also desynchronize the mu activity (Hobson & Bishop, 2017; Pfurtscheller & Neuper, 1997). These findings were supported by studies using EEG and concurrent fMRI-EEG in movement related tasks (Mizuhara, 2012; Ritter, Moosmann, & Villringer, 2009; Yin et al., 2016).

Using EEG, Oberman et al. (2005) reported evidence that they interpreted as MNS impairment in individuals with ASD. They measured mu rhythm suppression (8-13 Hz) in the sensorimotor cortex as an index of MNS activation, and compared mu suppression in ASD and TD participants viewing and performing actions. Their finding that mu suppression was decreased in participants with ASD was used as an argument in favor of the "broken MNS" theory of ASD. However, these results were not replicated by the follow-up studies (Fan et al., 2010; Gowen & Hamilton, 2013; Raymaekers, Wiersema, & Roeyers, 2009; Sotoodeh et al., 2019; Southgate & Hamilton, 2008). The origin of these discrepant results can be attributed to heterogeneity in autism symptoms (Fan et al., 2010), difference in age range (Raymaekers et al., 2009), in methods of recording brain activity, and in stimuli used (Hamilton, 2013). Therefore, the bases of the atypical MNS activation in ASD reported by previous studies remains unclear (Southgate & Hamilton, 2008). Differences in results could also be due to differences in early visual processing. Indeed, reduced attention to social stimuli (Klin et al., 2002), reduced response to BM (Blake et al., 2003), and reduced understanding of complex visual information have been documented in ASD (Behrmann et al., 2006).

Activation in the mu frequency band reflects a link between vision and perception of action, translating "seeing" to "perception of action" in the motor cortex (Pineda, 2005; Sabate et al., 2012), and mu rhythm depends on visual stimulation type (Cheng et al., 2008; Muthukumaraswamy & Johnson, 2004; Pfurtscheller & Da Silva, 1999).

Given that the integrity of the visual system is essential for BM processing, it is possible that abnormal visual processing in ASD could cause abnormal response within the MNS (Southgate & Hamilton, 2008). A recent study (Dumas et al., 2014), indeed, suggested a more complex picture. The researchers investigated mu-suppression in individuals with ASD over the whole brain, for two frequency sub-bands (low frequency range: 8–10 Hz and high frequency range: 10–13 Hz). Their results replicated the finding of a MNS dysfunction in individuals with ASD for both frequency bands (8–13 Hz) at the C3/C4 electrodes. However, the segregation of the mu band into two sub-bands revealed a normal response (i.e., similar suppression in both groups) on short mu sub-band, in contrast with an abnormal response in ASD participants of the long mu sub-band. The whole brain and source level analyses revealed that this altered mu modulation was related to a joint implication of an alpha suppression deficit over occipito-parietal regions, and to an abnormal increase of alpha activity over the frontal regions in ASD participants. In addition, a recent study (Sotoodeh et al., 2019) revealed that children and adolescents with ASD have preserved perception of BM, as indicated by similar mu suppression, as an index of MNS activity, during the observation of PLDs and real videos.

At the neural level, reduced visual information could result in a decreased activation in brain regions normally associated with social and movement perception (Schultz, 2005). Individuals with ASD show atypical neural processing in brain regions involved in the visual perception of social information such as facial expression or eye gaze (Pelphrey & Carter, 2008), and in brain regions related to action perception, social cognition and action perception such as the STS, that is involved in the perception of BM (Saygin, 2007) and movement intention (Castelli et al., 2002); The STS region activation relies on information provided by eye movements and visual system (Pelphrey et al., 2005).

To create an experimental paradigm to measure perception ability in participants with ASD, we used a complex method to control for any possible factor that may impact on perception of action in this population. Most importantly, we recorded eye movement, in order to control for visual information used in each population and test whether an impairment in mu suppression (as reported in some previous studies) could be due to participants with ASD attending to different aspects of the stimulus during the perception of BMs.

Previous studies had additional limitations. First, while neuroimaging studies using fMRI have a high spatial resolution, they have a limited temporal resolution. Second, most studies did not control where participants were looking, and their results may be affected by the abnormal visual attention of ASD participants (Kröger et al., 2014). To address these limitations, the present study used eye-tracking glasses to monitor where participants were looking during stimuli presentation. The ability to interpret others' actions relies on the MNS, and the MNS function can be indexed by power suppression in the mu and beta bands, with increased mu and beta suppression revealing better perception (Simon & Mukamel, 2016). Therefore, we used mu (8–13 Hz) and beta (15–25 Hz) power suppression as an index of BM perception to address the temporal limitation in previous studies. Based on previous literature we hypothesized that (1) we would not find differences in mu and beta suppression between participants with and without ASD viewing PLDs in the present study, (2) action perception would be altered in children with ASD with normal IQ scores (>70) viewing three different types of stimuli, and (3) that participants with ASD would have a different pattern of eye movements to the PLDs in comparison of TD participants. Finally, we hypothesized that there would be relationship between fixation duration to the stimuli and mu and beta suppression in the participants (4),

reflecting the role of visual input into the action perception system.

2 | METHOD

2.1 | Participants

G*Power was used to determine our sample size (Faul et al., 2007) based on previous results by Nackaerts et al. (2012), who reported an effect size of 1.16 in the difference between ASD and controls for difference in BM recognition, indicating that we needed at least 13 participants per group to have 80% power to detect a difference between groups with an alpha = 0.05. A total of 32 children participated the study. In the ASD group, 16 children (three girls) clinically diagnosed with ASD (age 8–17) were recruited from a special school for children with ASD. In the TD group, 16 age-matched typically developing (three-girls) children (age 7–16) were recruited from school for typically developing children (see Table 1). In our education system, all children undergo an assessment before entering to school each year. Children who have physical and/or intellectual disabilities are excluded from typical schools and start their education in schools for children with special needs. Our TD participants were recruited from schools for children without disability, therefore, without any intellectual disability or ASD. The Autism Diagnostic Interview-Revised (ADI-R: Lord et al. (1994) was used by a clinical psychologist to confirm the autism diagnosis of ASD participants. All participants' non-verbal IQ scores were measured with the Leiter International Performance Scale (Leiter: Roid et al. (2013)), so as to ensure none of them had an intellectual disability (scores above the Intellectual Disability [ID] threshold of 70). Leiter consists of a battery of tests that measures the level of nonverbal IQ, making it a very useful tool for deaf children and children with ASD. The Leiter can be used for age 4–20 years. It measures Visualization, Reasoning, Attention, and Memory (Martínez-González & Piqueras, 2018). IQ scores were significantly higher in TD children than in ASD children (see Table 1), a finding that is consistent with the high prevalence of intellectual disability (ID) in autism (Hoekstra et al., 2009). To minimize the potential effect of this between-group difference, IQ score was included as a covariate in all analyses (see discussion for details). To determine autism severity in participants, the Gilliam Autism Rating Scale (GARS: Gilliam, 1995) was employed for ASD group. The GARS has four subscales. Each subscale describes behaviors that are symptomatic of ASD (Stereotyped Behaviors, Communication Difficulties, Social Interaction, and Developmental Disturbances). The GARS is suitable for people of 3–22 years, and is answered by parents or professionals in approximately 10 minutes. This test has a standardized mean for children with ASD of 100 ± 15, and higher scores reveal greater autism severity, and lower scores milder autism severity. Our sample of participants had a score of 93.3, putting them in the average range for severity (Table 1).

All participants were right-handed and had normal or corrected to normal vision and had not any other medical, psychological and developmental disorder. Handedness of participants was assessed with Edinburgh Handedness Inventory (Robinson, 2013). The parents or caregivers of all participants provided written informed consent, while the children gave their verbal assent to be included in the study. All research procedures were approved by the local ethics committee at Ferdowsi University in accordance with the Declaration of Helsinki. Informed consent was obtained from all parents and caregivers of participants included in the study.

2.2 | Stimuli

The stimuli consisted of video-clips featuring Point Light Displays (PLDs) of a male adult in motion ("walking," "cartwheeling," and "free-throwing"). Those PLDs were created by attaching thirteen reflective markers to the actor's joint and showed as white light on a dark screen. The PLDs were displayed at a visual angle of 45° to let participants watch all four limbs correctly. A baseline scrambled condition was used too, in which series of dots were randomly blinking in

TABLE 1 Demographic data of participants

	ASD (Mean±SD)	TD (Mean±SD)	T	*p*
Age	11.3 ± 2.3	10.9 ± 3	0.480	.63
IQ	76.8 ± 5.07	106.06 ± 13.24	−8.23	.001*
Severity of Autism (GARS#)	93.3±11.4 Range 73–113			

*$p < .05$.

#Gilliam Autism Rating Scale (GARS: Gilliam, 1995).

their location. The baseline condition was created to be as similar to the PLDs as possible in terms of visual content (white dots on a black screen).

2.3 | Procedure

The experiment was divided in two studies. Both took place in a dark and quiet room that was acoustically and electromagnetically shielded. Participants sat in front of a 17″ LCD screen (LG, L1753S-SF©) placed 70 cm away from them. The viewing angle was $17^{\circ} \times 17^{\circ}$ and the stimuli were presented at the center of the screen.

2.3.1 | Experiment 1: EEG

In the first experiment, participants freely viewed each PLDs for 80s (at least 40 repetition of each action) on the computer screen. The stimuli had a size between 20 and 25 cm in width and between 25 and 30 cm in height on the screen. They were presented in a random order (Figure 1). The first and the last 10 seconds of each recording were removed to eliminate the possibility of attentional transition due to initiation and termination of the stimulus. The baseline condition was presented before each trial. Similar to previous studies (Raymaekers et al., 2009; Ulloa & Pineda, 2007), participants were instructed to maintain their attention on the PLDs during their presentation. EEG was recorded using FlexComp (Thought Technology Ltd) at C3, C4 according to 10–20 international systems of electrode placement. These electrodes locations have been used in previous studies to reflect the activity of the MNS (Pineda & Hecht, 2009; Ulloa & Pineda, 2007). Two earlobe electrodes were attached to each ear as reference and ground electrodes. EEG was recorded with a sample rate of 256 Hz. Before and after each recording session, the impedance of the electrodes was measured in order to confirm it was below 5kΩ. Data were epoched offline in 2-s segments. Artifact rejection was performed out in two steps: First a 50 Hz notch filter was used to filter line noises. The EEG from individual trials was visually inspected for eye blinks, muscle, and technical artifacts and corrected. Segments with remaining artifacts exceeding ± 100 micro volt in any EEG channel were rejected. Then, cleaned data were analyzed. The average number of rejected epochs whiting the ASD group was 5.06 ± 0.7 and for TD group was 4.9 ± 0.58. There were no differences between groups in rate of data rejection ($t(30) = 0.68$, $p = .50$). Second, The Fast Fourier Transforms (FFTs) were performed on the 2-s clean EEG segments (Muthukumaraswamy & Johnson, 2004; Raymaekers et al., 2009).

2.3.2 | Experiment 2: Behavioral

Action recognition

A sample trial of the action identification task is depicted in Figure 2. The experimenter informed participants that a total of three animations would be presented. A fixation cross (2 × 2 cm) was then presented at the center of the screen for 1.5 s, followed by a PLDs displayed up to four times (2s per instance). Each stimulus was repeated four times in each trial and each trial was repeated three times in random order to decrease prediction effect. Participants' gaze was recorded simultaneously during action recognition test with an eye-tracking device. Participants were asked to recognize the presented PLDs and respond as fast and accurately as possible, by means of a right-handed key press (V for "walking," B for "free-throwing," N for "cartwheeling"). We used these three keys because they are at the center of keyboard and were easy to press without any extra movement of hand or fingers. Participants' Response Time (RT) and accuracy (correct recognition= True, incorrect recognition = False) were recorded. If participants did not provide an answer after the fourth presentation of the PLDs, or responded before finishing first presentation of the stimuli, the trial was considered

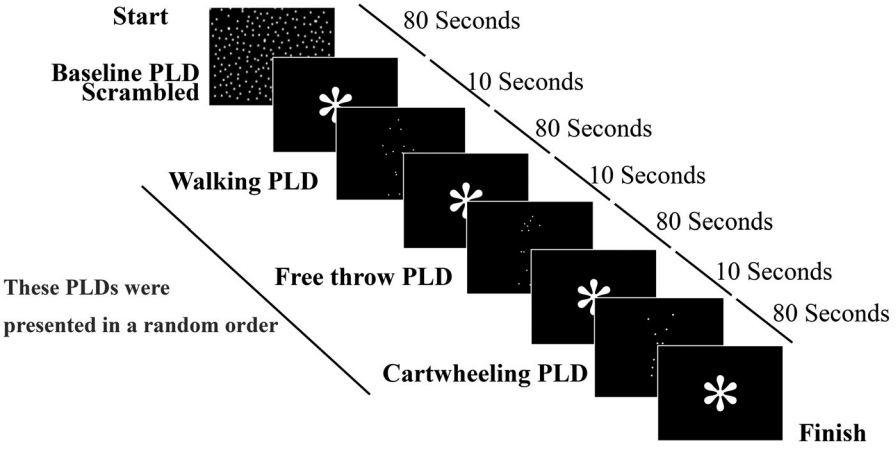


FIGURE 1 Schematic view of PLD stimuli

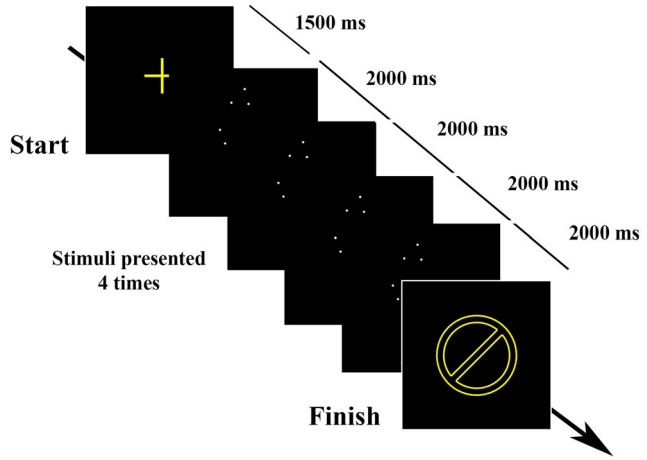


FIGURE 2 Example of a trial for Study 2

to be missed. To avoid order effect, the participants participated in the experiment 1 and 2 in a counter balanced order.

Eye-tracking

Participants' gaze behavior during the action recognition test was captured using a mobile eye-tracking system (SensoMotoricInstruments ETG-2 binocular mobile eye-tracking www.smivision.com). Eye movements were recorded with two small cameras in the septum of the glasses and matched to the video-recordings from a scene camera located in front of the glasses (Vabalas & Freeth, 2016). A three-point calibration procedure was used based on the manufactory suggestion. Eye movements (fixations, saccades, and blinks) were defined using the manufacturer's standard algorithms.

2.4 | Data analysis

2.4.1 | Experiment 1: EEG

EEG signals that were captured, amplified and filtered from 0.1 to 64 Hz using an analog elliptic band pass filter. In addition, a 50 Hz notch filter was performed (Ghoshuni et al., 2013). We aimed at measuring the suppression of mu (8–13 Hz) and beta (15–25 Hz). Mu suppression was computed for low mu (8–10 Hz) and high mu (11–13 Hz) separately, because previous studies showed that low mu (8–10 Hz) was more suppressed during action observation than during action execution (Simon & Mukamel, 2016). The logarithmic transformation of the ratio power was used because ratio power data are intrinsically non-normal (Ulloa & Pineda, 2007). To compute the suppression index, we used following equation:

$$\mathrm{SI} = \log_{10}\left(\frac{EC}{BC}\right)$$

SI = Suppression Index

Ec = Experimental Condition

Bc = Baseline Condition

Log values below zero indicate suppression in EEG amplitude, while log values above zero indicate enhancement in EEG amplitude (Perry et al., 2010; Pineda & Hecht, 2009; Raymaekers et al., 2009). For each band (low mu, high mu, beta), the log values were analyzed using a 2 (Group: ASD and TD) × 2 (Hemisphere: Right and Left) × 3 (Condition: "walking," "cartwheeling, "free-throwing") ANCOVA with IQ and eye-movements (Fixation duration and Fixation count) as covariates. See S1 and S2 supplementary files for correlations.

2.4.2 | Experiment 2

Action recognition

The "number of correct responses" and the "identification speed" were used as independent variables. The number of stimuli presentation that participant answered correctly to the test were considered as "number of correct responses" and the time between stimuli presentation to response considered as "identification speed." Incorrect and missed trials were not included in the analysis. Incorrect trials consisted of trials for which an incorrect key press was made. Missed trials consisted of trials for which the response was made after 8000 ms (after four repetition) or earlier than 2000 ms (before first repetition). Given that responses were made after stimuli presentation, responses made before 2000 ms were removed from analysis (8.7 % for ASD and 4.2 % for TD, $p > .05$).

Number of correct responses was compared between two groups by independent *t*-tests also a Chi-square statistic was used to test the distribution of responses elicited in the first, second, third, and fourth time of display.

Eye-tracking data

Eye-tracking data were further processed with the SMI BeGaze 3.5 software (Vabalas & Freeth, 2016) during action recognition test. We chose two Areas Of Interest (AOIs): body and background (see Figure 3). The proportion of time spent fixating in the body AOI (fixation duration) and the number of saccades landing on the body AOI were calculated and used for each condition and each participant.

Fixation duration and saccades were analyzed using a 2 (Group: ASD, TD) × 3 (Condition: "walking," "free-throwing," "cartwheeling") mixed Analysis of Covariance (ANCOVA) IQ score inserted in the model as Covariate. Simple effects were further investigated, and Bonferroni correction for multiple comparison was applied whenever necessary.

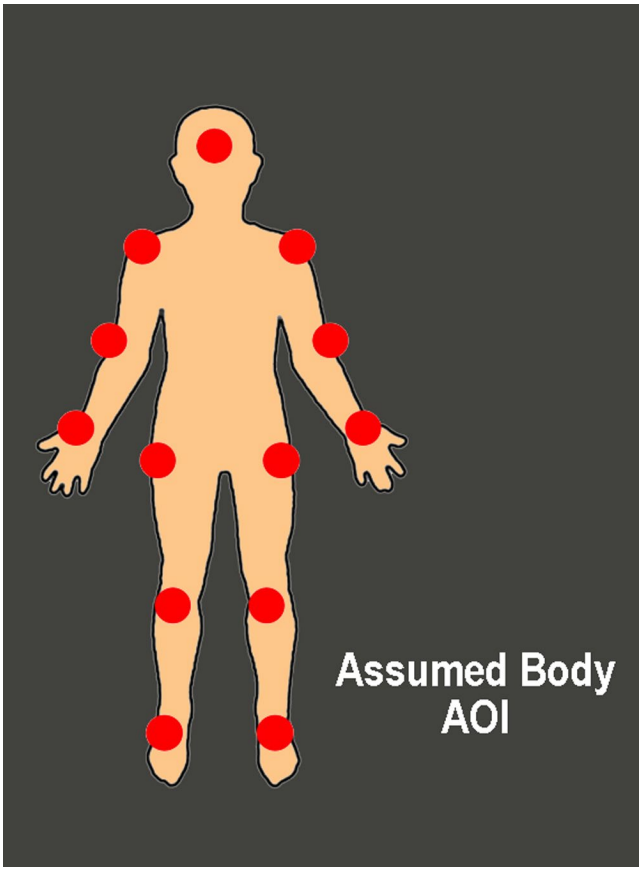


FIGURE 3 Areas of interest

2.4.3 | Relationship between two experiments

We explored the relationship between action recognition (number of correct answers and reaction time) test and eye movements (fixation duration and saccades) also between mu suppression in different conditions ("walking," "free –throwing," and "cartwheeling") and eye movements (fixation duration and saccades). Furthermore, multiple regression analyses were conducted to find predictors of mu and beta suppression between IQ, age, and behavioral results (eye movements and identification test).

3 | RESULTS

3.1 | Electrophysiological

Figure 4 reveals that both groups exhibited suppression for all three actions in different bands. Although all groups showed more suppression in lower mu than in beta and higher mu, there was not any significant effect of band ($F_{2,58} = 0.69$, $p = .50$). For lower mu, results of ANCOVA showed that there was not any significant effect of group ($F_{1,29} = 0.22$, $p = .64$), hemisphere ($F_{1,29} = 0.08$, $p = .77$), and conditions ($F_{2.58} = 0.51$, $p = .60$). In addition, the interaction effect of condition × group, condition × hemisphere, and condition × group × hemisphere was not significant ($p > .05$).

Similarly, for higher mu, the results of the ANCOVA revealed no significant effect of group ($F_{1,29} = 0.51$, $p = .48$), hemisphere ($F_{1,29} = 0.46$, $p = 0.50$), and conditions ($F_{2,58} = 0.24$, $p = .78$). The interaction of condition × group, condition × hemisphere, and condition × group × hemisphere was also not significant ($p > .05$).

For the beta band, the ANCOVA revealed that there was not any significant effect of group ($F_{1,29} = 1.18$, $p = .28$), hemisphere ($F_{1,29} = 0.16$, $p = .68$), and condition ($F_{2.25} = 0.16$, $p = .68$). The interaction of condition × group, condition × hemisphere, and condition × group × hemisphere was not significant ($p > .05$).

3.2 | Action recognition test

There was a significant difference between number of correct responses ($t(30) = -3.27$, $p = .003$). Participants with ASD had lower number of correct responses (Mean = 6.75, SD = 2.04) than the TD group (Mean = 8.62, SD = 1.02), as indicated on Figure 5. Results of Chi square test of homogeneity revealed that ASD and TD groups did not share the same distribution in the number of correct responses ($\chi^2 = 10.74$, p = .013). Figure 6 depicts more information about responses to each stimuli condition. The colors indicate speed of response to stimuli.

3.3 | Eye-tracking data

For fixation duration, there was no significant effect of group ($F_{1,29} = 0.71$, $p = .40$), condition ($F_{2,58} = 0.16$, p = .84) and Group by Condition ($F_{2,58} = 0.23$, $p = .79$) were not significant.

In contrast, as shown on Figure 7a, the number of saccades differed significantly between groups ($F_{1,29} = 6.77$, $p = .014$, $\eta_p^2 = 0.18$), such that TD participants had more saccades in the body AOI (mean = 39.31, SD = 10.68) than ASD participants (mean = 31.04, SD = 7.13). In addition, the experimental condition significantly affected the number of saccades ($F_{2,62} = 36.15$, $p < .001$, $\eta_p^2 = 0.53$), such that the "walking" and "free-throwing" conditions were associated with more saccades than the "cartwheeling" condition Figure 7b). Further analysis revealed more saccades for "free-throwing" than "walking" ($p = .004$) and "cartwheeling" ($p < .001$), and a more saccade for "walking" than "cartwheeling" ($p < .001$). However, the interaction between Group and Conditions was not significant ($F_{2,58} = 0.23$, $p = .79$).

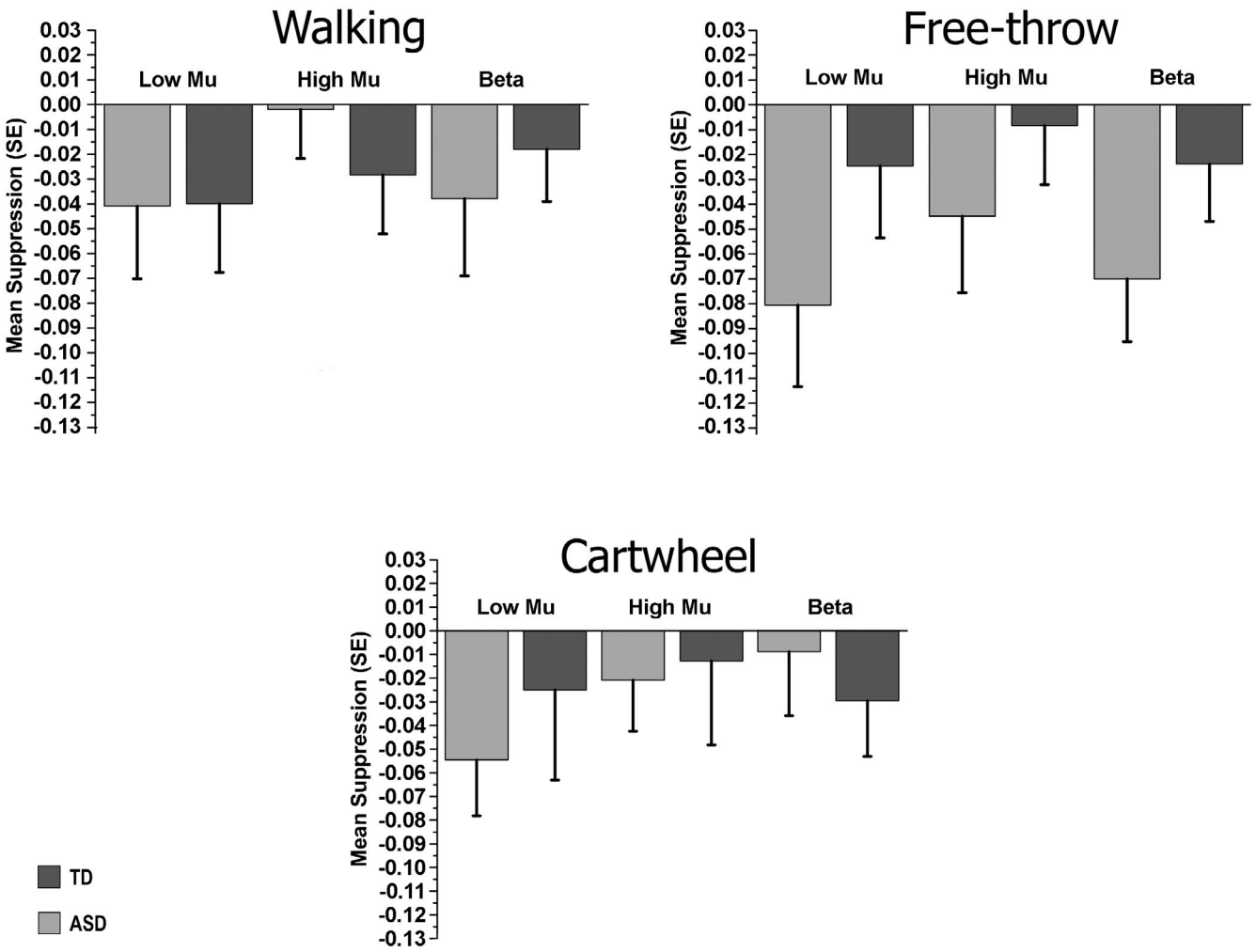
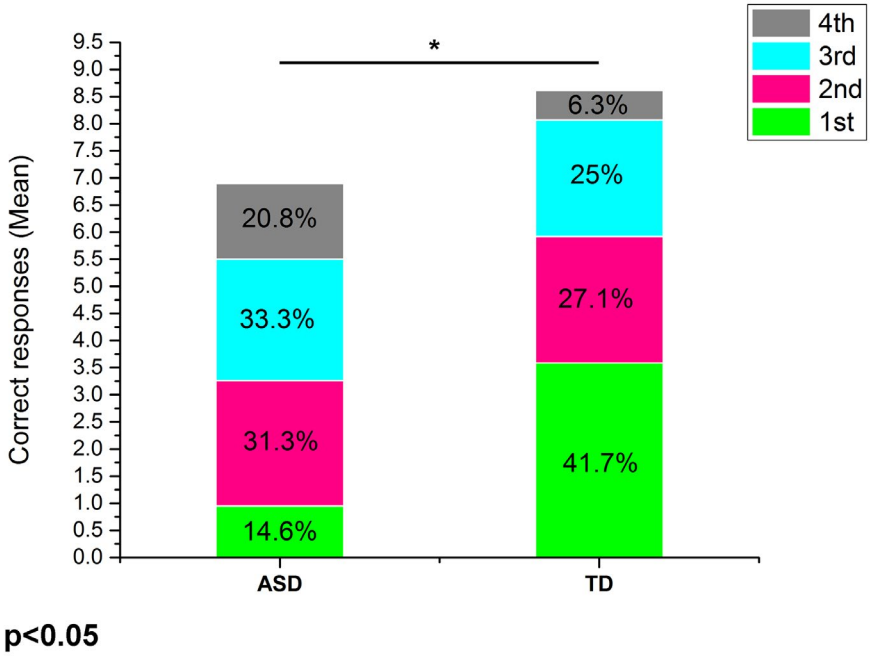


FIGURE 4 Mean (se) suppression index in different bands, groups, and conditions



* p<0.05

FIGURE 5 Means of the number of correct responses and speed of identification and percent of correct responses in each time. Most of TD participants responded correctly in their first answer, however, most of ASD participants answered correctly in their third answer.

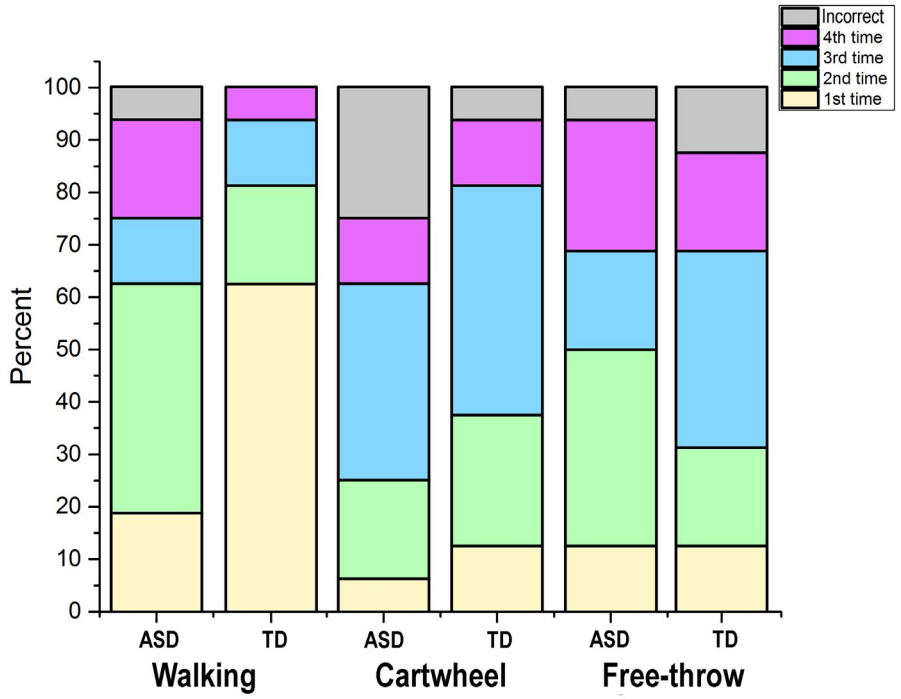


FIGURE 6 Percent of distribution speed of identification for different stimuli. This graph reveals that walking, free-throwing and cartwheeling were easiest conditions for recognition, respectively.

3.4 | Correlation between EEG and eye movements

Results of Pearson correlation test (supplementary file S2) revealed that there was a significant relationship between lower mu, higher mu, and beta and number of saccades and fixation duration ($p < .05$).

4 | DISCUSSION

Three decades of research on perception of BM in individuals with ASD have yielded conflicting results (Cusack et al., 2015; Kaiser & Pelphrey, 2012; Wang et al., 2015) as to whether BM perception is affected in ASD. Discrepancy between previous results may be due to differences in factors such as age, IQ, stimulus type, and task demands. We reasoned that children with ASD and without intellectual disability may not be impaired at perceiving BM, because of their ability to use compensatory mechanisms during stimuli perception (Actis-Grosso et al., 2015). The aim of the current study was thus to investigate whether the ability of children with ASD to perceive BM was intact, using EEG, eye-tracking, and behavioral measurements.

4.1 | EEG: Preserved MNS function in ASD

Modulation of EEG beta and mu oscillations power over sensorimotor cortices was recorded during the observation of BM video clips ("walking," "free-throwing," and "cartwheeling"). The results showed that, in all three conditions, there was a mu (low = 8–10 Hz, high = 10–13 Hz) and beta (15–25 Hz) suppression in both groups, reflecting similar MNS engagement in the task (Dumas et al., 2014). These results are in agreement with previous studies that did not find a MNS dysfunction in ASD (Bernier et al., 2013; Dumas et al., 2014; Fan et al., 2010; Raymaekers et al., 2009; Sotoodeh et al., 2019). Both groups also showed more suppression in low mu (8–10 Hz) than high mu (10–13 Hz), replicating previous studies in TD children (Frenkel-Toledo et al., 2014) and in children with ASD (Dumas et al., 2014). Thus, low mu suppression appears to be a better electrophysiological index of mirror system activity than the whole frequency range (Dumas et al., 2014).

Previous studies have established that prior experience of particular action influences action perception and observation processing (Hecht et al., 2001; Schütz-Bosbach & Prinz, 2007). A series of studies have shown increased activity in the MNS with a higher degree of expertise for certain actions (Calvo-Merino et al., 2005). Increased MNS activation following experienced action may relate to greater engagement of predictive processes (Kilner et al., 2007) or better perception of observed action (Rizzolatti & Sinigaglia, 2010). Participants with ASD in the current study had daily physical activity and sport time in their school. The familiarity with the actions presented in the experiment may have affected the results. This may be worth being taken into account by future studies.

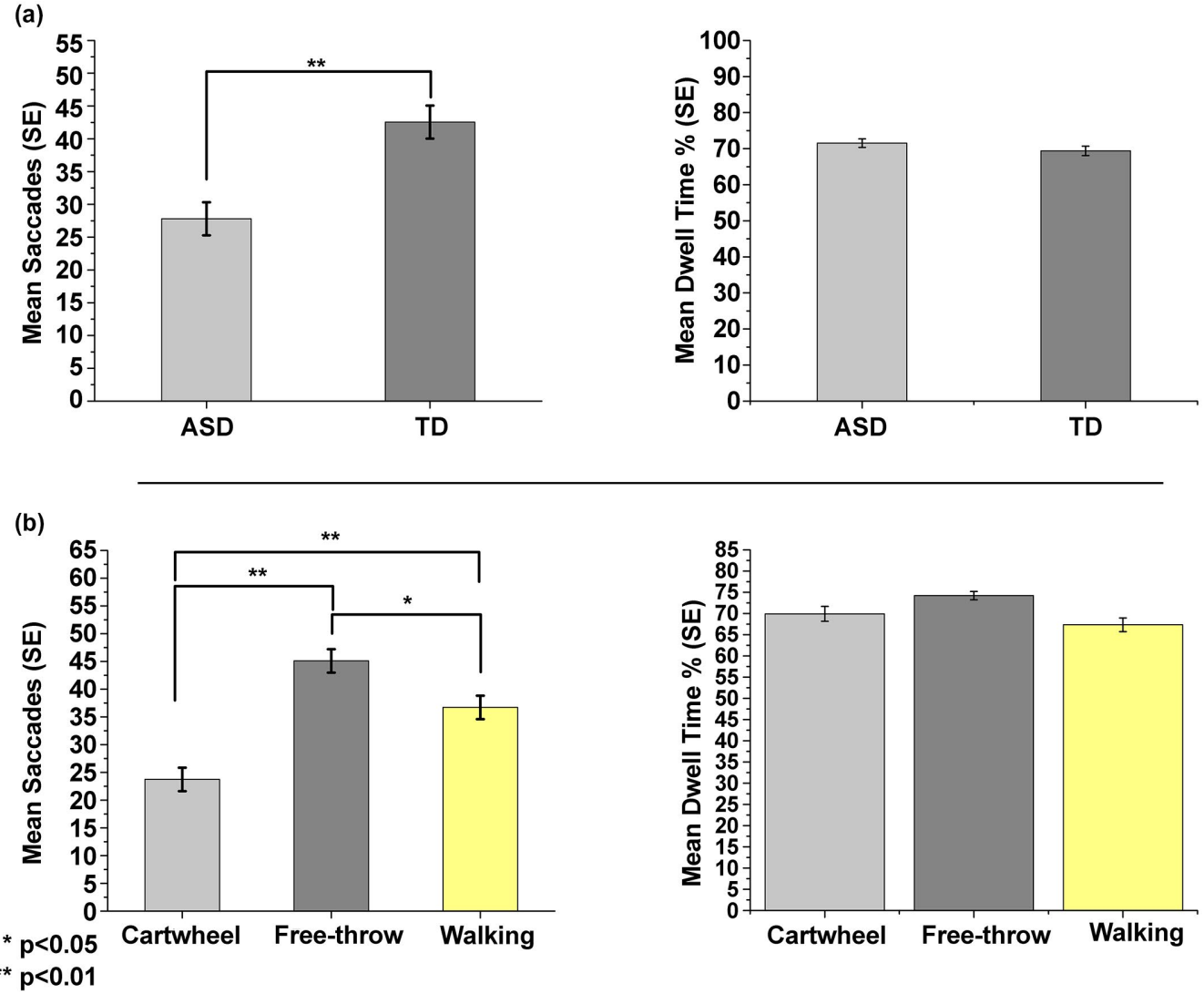


FIGURE 7 Mean and standard error of saccades and dwell time (fixation time) in different groups (a) and different conditions (b)

4.2 | Behavior: less accurate action recognition in ASD

In the present experiment, children with ASD experienced difficulties in PLDs BM recognition task. These findings are consistent with previous studies reporting deficits in recognition of BM in children and adolescents with ASD (Blake et al., 2003; Koldewyn et al., 2011; Wang et al., 2015). Our results are also consistent with the results of Nackaerts et al. (2012) who showed decreased accuracy in ASD for identifying "a person" in a series of scrambled or intact PLDs. However, most previous studies in which adult participants were included revealed no accuracy differences for distinguishing BMs from scrambled motion (Freitag et al., 2008). A possible explanation for those discrepant results is the different tasks used in our study and previous studies (Murphy et al., 2009; Nackaerts et al., 2012; Saygin et al., 2010). Regardless of differences in accuracy, there was a similar pattern of response in both groups. Stimuli that were easier to recognize for children with ASD were also easier for TD children. These findings replicate results of previous study by Cusack et al. (2015) and Wang et al. (2015). Although children with ASD were less accurate in their responses, it does not mean that they were not capable at all to recognize actions in PLDs. They may have been less accurate because they needed more time (Hubert et al., 2007; Moore et al., 1997; Wang et al., 2015). This result might be related to executive dysfunctions in ASD, that is, problem with functions such as inhibition, working memory, attention and decision making (Cusack et al., 2015; Hill, 2004; Van der Hallen et al., 2019). Another reason for these results may be that children with ASD had difficulty understanding the test instructions, were less motivated, or had difficulties labeling the PLDs (Parron et al., 2008; Van der Hallen et al., 2019). Moreover, based on the weak central coherence hypothesis in autism (Happé & Frith, 2006) individuals with ASD focus more on

details within a visual stimuli due to increased processing of local detail and/or failure to integrate information related to perceive the overall whole or global motion processing. It is possible that individuals with ASD have difficulties in integrating information captured from visual system and convert this information to an output and response to the action recognition test. There is a need for more studies in this area, that will include a control for the level of arousal and visual behavior of individuals with ASD during action recognition and EEG recording.

4.3 | Altered visual preferences for BM in ASD

Both the TD and ASD groups attended more to the "free-throwing" stimuli than to the "walking" and "cartwheeling" stimuli. However, those with ASD showed less looking at BM overall, as indicated by their decreased number of fixations on the area of interest "body" compared to TD participants.

Our results replicate those of previous studies in which similar stimuli were used (Annaz et al., 2012; Nackaerts et al., 2012). They are also consistent with the results of Klin et al. (2009) who used animated audio-visual stimuli. Remarkably, our results are in agreement with those of previous studies despite the fact that the present study included children who were older than those included in previous studies (8–17 years old, while 3–7 years old were tested in Annaz et al. (2012) and 2 years old were tested in Klin et al. (2009)). This suggests that the lack of preferential attention to BM is present in children and adolescents with ASD across a wide age range. However, more studies are needed to show possible differences in visual scanning patterns of individuals with ASD when attending to the different parts of stimuli (head, body, and different limbs) and test whether this reflects different patterns of attention (i.e., global versus local).

4.4 | Relationship between eye-movements and MNS functions

Results of the current study indicate that there is a relationship between eye-movements and MNS functions. Specifically, the more the participants focused on the PLDs, the more they displayed mu and beta suppressions. These results are really important, and could challenge the results of previous studies that had not controlled for visual attention of their participants and found a possible deficit in MNS functions of individuals with ASD. However, since eye movements were not recorded simultaneously with EEG in the present experiment, the results should be interpreted carefully.

Based on the results of those two experiments, we can conclude that the MNS of individuals with ASD is not broken, but that they do exhibit difficulties with processing of body movements.

5 | LIMITATIONS

One of the limitations of the current study was the difference in IQ between TD and ASD groups, which may have impacted the behavioral differences between groups, but we tried to mitigate it by controlling for IQ at the statistical level. Another limitation is that ASD participants had physical activity classes in their schedule, and familiarity with the BM tests in the present experiment may have affected our results. Moreover, we could not check the motor experiences of participants prior to the study. Finally, we recorded eye-movements of participants when they were performing action recognition tests.

6 | CONCLUSIONS

In order to better understand the relationship between MNS function and visual attention, we recommend that future studies record eye-movements of participants concurrently with EEG. We also recommend to match participants for IQ level and survey participants for current/past motor training because both IQ and previous experiences may have affected action perception in participants in the reported study. Future research should also examine whether age has an effect on BM perception in ASD participants in a larger sample.

In conclusion, our results revealed that, although children with ASD have abnormal gaze behavior and are less accurate in recognizing actions from PLDs, neural mechanisms that relate to action understanding (MNS: i.e., beta and mu suppression) are preserved in ASD, and that the differences between groups in behavioral tests may be affected by other factors.

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CONFLICTS OF INTERESTS

There is no conflict of interest to declare.

AUTHOR CONTRIBUTIONS

Sotoodeh: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Software;

Validation; Visualization; Writing-original draft; Writing-review & editing. **Taheri-torbati:** Funding acquisition; Project administration; Resources. **Hadjikhani:** Formal analysis; Writing-review & editing. **Lassalle:** Data curation; Formal analysis; Writing-original draft; Writing-review & editing.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

Table S1

Table S2

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