Atypical Biological Motion Perception in Children with Attention Deficit Hyperactivity Disorder: Dissociating the Roles of Local Motion and Global Configuration Processing

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Abstract

The ability to perceive biological motion (BM) is crucial for human survival and social interaction. Plentiful studies have found impaired BM perception in autism spectrum disorder characterized by deficits in social interaction. Children with attention deficit hyperactivity disorder (ADHD) often exhibit similar deficits in social interaction, but few studies have investigated BM perception in ADHD. Here, we compared the differences in abilities to process local kinematic and global configurational cues, two fundamental abilities of BM perception, between typically developing (TD) and ADHD children. Then, we further investigated the relationship between BM perception and social interaction skills measured by the Social Responsiveness Scale (SRS) and examined the contributions of potential factors (e.g., gender, age, attention and intelligence) to BM perception. Results revealed that children with ADHD exhibited atypical BM perception with a clear dissociation between local and global BM information processing. Local BM processing ability was largely related to social interaction skills, whereas global BM processing ability would significantly improve with age. Critically, general BM perception (i.e., both local and global BM cues) was affected by sustained attention ability in ADHD. This relationship was mainly mediated by Reasoning Intelligence. These findings elucidate the atypical biological motion perception in ADHD and the potential factors related to BM perception. Moreover, this study provides new evidence for local BM perception as a hallmark of social cognition and advances the comprehensive understanding of the distinct roles of local and global processing in BM perception and social cognitive disorders.

Introduction

Attention deficit/hyperactivity disorder (ADHD) is a common developmental disorder. The prevalence of ADHD in children and adolescents is between 2% and 7%, with an average of around 5%[1]. Besides the well-established core symptoms of ADHD (including a deficit of sustained attention, hyperactivity, and impulsivity), some ASD characteristics, such as dysfunctions in social communication and social interaction, have also been frequently reported in ADHD children[2-4]. However, experimental studies of social cognition in ADHD are still scarce. Some studies described worse

performance in tasks of social cognition. Among them, impaired theory of mind (ToM) and emotion recognition are most frequently reported[5-7]. It is difficult for children with ADHD to recognize others' emotions and purposes. Other social cognition processes in ADHD are unclear. Further exploring diversified social cognition (e.g., biological motion perception) will provide a new understanding of impaired social function in ADHD. Moreover, recent studies revealed that the social cognition in ADHD can potentially vary with different factors at the cognitive, pathological, or developmental levels, such as general cognitive impairment[5], the severity of symptoms[8], or age[5]. Yet, how these factors relate to the dysfunctions of social cognition in ADHD is still in its infancy. Bridging the gap is important because this knowledge can help depict the developmental trajectory of social cognition and find effective interventions for impaired social interaction in ADHD.

Biological motion (BM), namely the movement of a living creature, carries much information beyond bodily movements[9], such as intention[10], emotion[11], gender[12], and identity[13,14]. Since point-light displays (PLD) technology was used to depict human motions[15], it is possible to separate biological motion from other characteristics like shape and color. Considering the seminal impact on cognitive science, developmental and clinical neuroscience, BM perception has drawn significant attention from scientists. Some researchers attempted to deconstruct BM processing into more specific components. Our study concentrated on two fundamental abilities to process BM cues (Figure 1): the abilities to process local BM cues derived from major joint motion tracks and global BM cues of human configuration. Separable neural signals revealed two independent processing stages[16-18]. The ability to process local BM cues is genetically highly preserved[19]; for example, newly hatched chicks without visual experience exhibit a spontaneous preference for BM[20]. A similar finding is also reported in 2-day-old babies[21]. Local BM cues not only carry locomotive direction[22] but also aid in detecting life in the visual environment[23] without observers' explicit recognition or attention[24-27]. Moreover, the processing of local BM cues is unaffected by attention, relatively robust to masking noise and does not show a learning trend[27,28]. In contrast, global BM processing involves top-down processing, and attention plays a critical role in global BM perception[28,29]. Dispersed attention adversely affects its performance. Compared with local BM processing, global BM processing is

susceptible to learning and is heavily hindered by increasing mask densities[28]. In recent years, BM perception has received wide attention in studies of mental disorders[30], particularly in ASD, characterized by deficits in social communication and social interaction[31,32]. An important reason is that BM perception is considered a hallmark of social cognition. Individuals with deficits in BM processing exhibit worse social perception in daily life[10]. Especially in local BM processing, it was correlated with autistic traits, especially in the subdimension of social communication[19]. Therefore, it is essential to focus on revealing differences in BM processing between typical and atypical development, which will enhance our comprehension of social dysfunction in atypical development.

Few studies focused on BM perception in children with ADHD, compared with numerous studies of impaired BM perception in ASD. An EEG study found neuro-electrophysiological changes in processing BM stimuli in ADHD[33], whereas no behavioral difference existed, which could be improved by more carefully designed BM stimuli. Another study found that children with ADHD performed worse in BM detection with moderate ratios of noise[34]. Nevertheless, the accuracy of TD groups was also very low (i.e., poor performance), which indicated the inferior applicability of this paradigm. In short, factors such as inapplicable experimental designs may influence the precision and reliability of the results. Despite some preliminary hints, systematic evaluation of BM perception in ADHD is warranted.

Therefore, the current study aims to examine BM perception abilities in children with ADHD. The first question to be addressed by this study is whether the BM perception abilities differ between TD and ADHD children. As mentioned above, BM perception is related to social interaction and has two fundamental components. Local BM processing ability is genetically highly preserved, while global BM processing ability shows a learning trend and needs the involvement of attention. ADHD is a neurodevelopmental disorder characterized by attention deficit and mostly accompanied by impaired social interaction. Therefore, the second question is whether BM perception is associated with social interaction ability in ADHD, and if so, which factors (e.g., attention) could affect BM perception in ADHD. To answer these questions, we utilized a stable and ingenious behavioral paradigm used in a previous study and made minor modifications to fit it to children[19]. This paradigm

combined an intact and a scrambled point-lighted walker with a noise mask to measure local and global BM information processing abilities. Using this paradigm, in Experiment 1, we compared the performance in processing two different BM cues (i.e., local and global BM cues) as well as their combination (i.e., both local and global cues) between TD and ADHD groups. Then, in Experiment 2, we collected the social interaction trait of participants to examine its correlation with the performance of BM tasks. Finally, we investigated the contributing factors of BM perception in ADHD and explored their potential relations.

Materials and methods

Participants

We recruited a total of one hundred and seventeen children with and without ADHD to enter this study. Eighty-one children met the ADHD diagnostic criteria of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5)[35]. The clinical diagnosis was first made by an experienced child and adolescent psychiatrist in the Child and Adolescent Psychiatric Outpatient Department of the Peking University Sixth Hospital, based on the ADHD Rating Scale. The Chinese version of the kiddie-schedule for affective disorders and schizophrenia-present and lifetime version DSM-5 (K-SADS-PL-C DSM-5)[36,37], a semi-structured interview instrument, was then implemented to confirm the diagnosis. Thirty-six typically developing (TD) children were from ordinary primary schools in Beijing and screened out the presence of ADHD, ASD, affective disorders and behavioral disorders by a trained psychiatrist. All subjects of ADHD groups have full-scale IQ above 75 (5th upper percentile) on Wechsler Intelligence Scale for Children-Fourth Edition, and all TD children had a full-scale IQ that fell above the 5th percentile on the Raven's Standard Progressive Matrices[38] which is used in measuring reasoning ability and regarded as a non-verbal estimate of intelligence. Exclusion criteria for both groups included: (a) neurological diseases; (b) other neurodevelopmental disorders (e.g., ASD, Mental retardation, and tic disorders), affective disorders and schizophrenia; (c) that would impact experiments completion; (d) taking psychotropic drugs or stimulants in 30 days. (e) previous head trauma or neurosurgery.

36 TD children (age = 9.09 ± 2.18, 14 male) and 39 children with ADHD (age = 9.88 ± 2.23, 28 male) participated in Experiment 1. Groups did not differ by age (t = -1.550, p = .126) but differed in sex ($\chi 2$ = 8.964, p = 0.004). 42 ADHD children (age = 9.34 ± 1.89, 27 male) participated in Experiment 2. They were naïve to the task and did not participate in Experiment 1. Participant demographic characteristics are shown in Table 1. All individuals of each group had a normal or corrected-to-normal vision and were naïve to the objectives of experiments. Written informed consent was obtained from the parents of all children before testing. The Institutional Review Board of the Peking University Sixth Hospital has approved this study.

Assessment

K-SADS-PL-C DSM-5

K-SADS-PL-C DSM-5 is a semi-structured interview instrument for evaluating mental disorders in children and adolescents aged 6–18 years[36]. It involved thirty-five diagnoses based on the diagnostic criteria of DSM-5. A trained psychiatrist concluded the diagnosis by interviewing the parents and child. Chinese version showed great psychometric criterion[37].

ADHD Rating Scale

ADHD Rating Scale is adapted from the ADHD diagnostic criteria of DSM[39], which requires parents or teachers to complete the scale independently. Its Chinese version has an excellent psychometric criterion and consists of 2 subscales[40]: inattention (IA, nine items) and hyperactivity-impulsivity (HI, nine items). Each item is rated on a four-point Likert scale ranging from 1 (the symptom is “never or rarely”) to 4 (the symptom is “very often”). The final results will create three scores: (1) IA dimension score, (2) HI dimension score, and (3) Total score. Higher scores indicate more severe ADHD symptoms.

Social Responsiveness Scale

Social Responsiveness Scale (SRS) is a widely used quantitative measure with 65 items to assess the severity of social impairment in many mental disorders[41], and the psychometric properties of the Chinese version are desirable[42]. It includes five

173 subdimensions: social awareness, social cognition, social communication, social
174 motivation, and autistic mannerisms. Each item is rated on a scale from 0 (never true)
175 to 4 (almost always true), with higher scores indicating worse social ability.

176 **Wechsler Intelligence Scale for Children-Fourth Edition**

177 Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) is widely used to
178 test comprehensive intelligence in individuals aged 6–18. It contains fifteen subtests
179 which comprise four broad areas of intellectual functioning: Verbal Comprehension,
180 Perceptual Reasoning, Working Memory, and Processing Speed. Scores of the four
181 broad areas constitute the full-scale intellectual quotient (FIQ).

182 **QB Test**

183 QB Test is a 15-min Continuous Performance Test (CPT) for assessing inattention
184 and impulsivity with a high-resolution infrared camera monitoring participant's
185 activity[43]. Previous psychometric studies have validated its good measurement
186 properties[44]. After the test was completed, several Q scores were calculated to
187 summarize participant performance. The Q scores were standardized based on
188 normative data matching gender and age. The higher Q score implies more abnormal
189 performance. In this study, we focused on the QbInattention, the Q score responsible
190 for sustained attention, particularly when children focused on tasks.

191 **Stimuli**

192 Stimuli were presented on a 14-inch monitor using MATLAB together with the
193 PsychToolbox extensions. All subjects completed experiments in a dim-lit room with
194 heads on the chinrest to ensure their eyes were 50 cm away from the monitor.
195 Point-light BM stimuli sequences adopted in this study have been used in previous
196 studies[45], which were derived from configurations of individual walking motion on a
197 treadmill and did not contain an overall translation. Each frame of BM sequences
198 consisted of 13 white dots representing the human head and major joints and was
199 displayed on a grey background. Each walking cycle lasted 1s with 30 frames. For
200 each trial, the initial frame of BM sequences was randomized. The whole
201 point-lighted BM walker presented about 5.7 ° visual angle vertically.

202 **Procedure**

203 In Experiment 1, 36 TD children and 39 children with ADHD were required to
204 complete three tasks that were similar to but slightly modified from the versions
205 implemented in our previous study[19] (Figure 2). Each trial began with a fixation cross
206 (0.6° * 0.6°). After a random 1200-1500 ms interval, the monitor displayed a BM
207 sequence specific to each task, lasting 2 s (60 frames). Task 1 (BM-Local) assessed
208 the ability to process local BM cues. 13 dots were randomly relocated within the
209 range of intact BM walker, which rendered global configuration destroyed and local
210 kinematics retained instead. After the display, we required children to press a left or
211 right button to indicate the motion direction of the unidentified creature (i.e.,
212 scrambled BM walker) as accurately as possible. Children received no feedback on
213 whether a right or wrong answer was given. There were 30 trials in total and 15 trials
214 for each condition (left and right). Task 2 (BM-Global) tested the ability to process
215 the global configuration cues of the BM walker. Children needed to judge whether
216 there was an intact walker in a mask. Each trial contained a mask consisting of two
217 scrambled target walkers (26 dots) within the boundary about 1.44 times the intact
218 walker. And the scrambled or intact version of the target walker was randomly
219 embedded into the mask. This procedure extracted global configuration cues from the
220 original BM sequence because two conditions (i.e., scrambled and intact walker)
221 contained the same information of local kinematics as the mask, and the local motion
222 cues were hence uninformative. The correct choice asked for using the global
223 component. To avoid learning the shape of the walker[24], we set target walkers
224 possibly facing one of five equally spaced directions from left to right. There were 30
225 trials composed of two conditions (intact or scrambled target). In Task 3
226 (BM-General), the intact target walker facing left or right was embedded into the
227 mask. The mask is similar to Task 2. Children were required to judge the facing
228 direction of the target walker (left or right). Because the mask was set to covey the
229 local BM cues consistent with the target walker, children could perform the task using
230 general (i.e., local + global) BM information. Task 3 was composed of 30 trials (15
231 for each facing directions). Other parameters of Task 2 and 3 were similar to Task 1.
232 Before each task, children practiced five trials to make sure good understanding. We

233 performed three tasks in a fixed order so that participants were naïve to the scrambled
234 walker and only made choices using local BM cues in Task 1.

235 In Experiment 2, 42 children with ADHD completed the same procedures as in
236 Experiment 1. Beyond that, their parents should fill in the Social Responsiveness
237 Scale (SRS) to assess social interaction.

238 **Statistics**

239 We carried out ANOVA to examine the difference in BM perception abilities between
240 TD and ADHD children and the Pearson correlation analysis to assess the relationship
241 between the accuracy of each task and the SRS score. General linear models and path
242 analysis were used to explore the roles of potential factors on BM perception. A p
243 value < 0.05 was considered statistically significant.

244 Results

245 **Children with ADHD exhibit atypical BM perception**

246 Figure 3 shows the mean accuracies (ACC) for both groups in the three tasks in
247 Experiment 1. We tested the difference in ACC between the TD and ADHD groups in
248 each task using one-way ANOVA (Gender as a covariate). In Task 1, the group
249 comparison revealed a significant difference ($F_{1,72} = 5.630$, $p = 0.020$, $\eta^2 = 0.073$).
250 Children are asked to judge the facing direction of the target walker using global BM
251 cues (Task 2) or general BM cues combining global with local BM cues (Task 3). TD
252 group have higher accuracies than the ADHD group (Task 2: $F_{1,72} = 12.600$, $p <$
253 0.001, $\eta^2 = 0.149$; Task 3: $F_{1,72} = 19.926$, $p < 0.001$, $\eta^2 = 0.217$). In all statistical
254 analyses, the main effects of gender were not significant (all $p > 0.05$).

255 **Atypical perception of local BM information predicted impaired social**
256 **interaction in ADHD**

257 Experiment 1 demonstrates that the abilities of BM perception were atypical in
258 ADHD. Our previous study revealed that local BM processing ability is heritable and
259 negatively correlated with autistic traits, especially in the subdimension of
260 communication[19]. In addition, substantial evidence indicates that children with ADHD
261 often have problems in social interaction. We expected that compromised social

interaction in ADHD might be associated with atypical local BM processing. So, we recruited 42 naïve children with ADHD to participate in Experiment 2 to explore this relationship. Their parents or caregivers familiar with children completed SRS (total scores = 54.64 ± 18.42). Thirty-three TD children had SRS scores (total score = 38.64 ± 12.47). The total SRS scores in the TD groups are significantly lower than those in the ADHD group (t = -4.277, p < 0.001). We found that children with higher total score of SRS performed worse in Task 1, i.e., the ability of local BM processing was negatively correlated to SRS total scores (r = -0.264, p = 0.022). Notably, significant correlations were also identified between SRS total score and global BM processing and between SRS total score and general BM processing (global BM perception: r = -0.238, p = 0.039; general BM perception: r = -0.359, p = 0.002).

In the further subgroup analysis, as seen in Figure 4, the correlation between the SRS total score and the ability to process local cues was only found in the ADHD group (ADHD: r = -0.461, p = 0.002; TD: r = 0.109, p = 0.547), particularly on subscales of social awareness, social cognition, social communication, social motivation (see Table 2 for complete information). However, no correlation was found between SRS scores and global or general BM processing in either ADHD or TD groups (all p > 0.05).

Reasoning intelligence and attention regulated BM processing

Experiment 2 revealed that local BM processing instead of global BM processing was related to social interaction. Then, which factors would regulate the difference in processing global BM cues? Previous meta-analysis studies of BM perception in ASD found mixed results about the effect of age and IQ on processing BM[31,32]. In addition, neural responses related to BM processing are strongly regulated by attention[29]. Did these factors play critical roles in BM perception in ADHD, a neurodevelopmental disorder characterized by attention deficit? To answer this question, we integrated data from the ADHD group in Experiment 1 and Experiment 2 (n = 80, one child did not complete QB test). Two linear models were built to investigate contributing factors: (a) *BM-global* = *age* + *gender* + *FIQ* + *QbInattention*; (b) *BM-general* = *age* + *gender* + *FIQ* + *QbInattention* + *BM-local* + *BM-global*. We screened factors with the largest contribution to the models by step-wise regression. For model (a), the

ability to process global BM cues was enhanced with age (standardized $\beta = 0.251$, $p = 0.025$). For model (b), higher FIQ, particularly on subdimension Perceptual Reasoning (standardized $\beta = 0.271$, $p = 0.005$), and more excellent global BM processing (standardized $\beta = 0.290$, $p = 0.004$) predicted better performance in general BM processing. Furthermore, as children grew up, the ability to probe general BM information increased (standardized $\beta = 0.365$, $p < 0.001$). It is worth noting that QbInattention had a highly negative correlation with Perceptual Reasoning ($r = -0.355$, $p = 0.001$) and general BM perception ($r = -0.246$, $p = 0.028$). Given the risk of collinearity, we further used path analysis to visualize these relationships post hoc (Figure 5). The result showed sustained attention (i.e., QbInattention) did not predict performance in BM-General (i.e., Task 3) directly. However, a significant indirect path via the ability of Perceptual Reasoning was found. In addition, as children with ADHD grew up, their performance in BM-General (i.e., Task 3) not only improved directly but enhanced via better processing of global BM cues. Moreover, we built model (c) to corroborate that the local BM processing was stable with age and unaffected by attention and IQ: (c) *BM-local = age + gender + FIQ + QbInattention*. No regressor has remained after step-wise regression.

In addition, we further built three models to explore the effects of Reasoning IQ and age on BM perception in TD children: (a) *BM-local = age + gender + FIQ*. (b) *BM-global = age + gender + FIQ*; (c) *BM-general = age + gender + FIQ + BM-local +BM-global*. No regressor has remained after step-wise regression in model (a). For models (b) and (c), there are positive relations between age and performance (BM-global: standardized $\beta = 0.396$, $p = 0.017$; BM-general: standardized $\beta = 0.330$, $p = 0.049$).

Discussion

Our study contributes several promising findings on atypical biological motion perception in ADHD. Specifically, we found that children with ADHD performed worse in processing local, global and general BM information than TD children. Notably, there was a clear dissociation between local and global BM information processing. The ability to process local BM cues, which is highly heritable, could predict deficits of social interaction in ADHD. By contrast, global BM processing,

which is largely shaped by experience, would significantly improve with age. Moreover, the results also unraveled the potential factors related to BM perception: Reasoning Intelligence played a mediating effect on the relationship between attention and general BM perception.

BM perception is a hot topic in the field of visual cognition. One critical reason is that BM naturally contains biological and social properties. BM processing has significant value in successful daily life, particularly in nonverbal communication[11,46] and adaptive behavior[29,47]. As an early emerging ability, BM can be discriminated in the newborn baby[21]. In typical development children, there is a linkage between BM perception and social cognitive abilities[48]. For example, 12-month-old infants showed social behaviors (i.e., following gaze) elicited by BM displays[49]. It is, therefore, of the supreme importance of BM to children's development of social cognition. This "social interpretation" of BM proposed that the ability to process BM may be taken as a measure of difficulties in social interaction[19]. An example is that poor performance of BM perception is a hallmark of impaired social function in children with ASD[10,50] . That implies that atypical BM perception may contribute to the deficits of social interaction in ADHD. Albeit we found a correlation between the SRS total score and the accuracy of each of the tasks in all participants, only a significantly negative correlation between the SRS total score and the accuracy of processing local cues was found in ADHD group in the further subgroup analysis, which provides preliminary evidence for the hypothesis and demonstrates that the local BM processing can predict impaired social interaction in children with ADHD. This finding is consistent with previous studies that revealed a common genetic basis for local BM processing ability and social communication[19]. In the subgroup analysis, however, we did not find a correlation between social interaction and global BM processing, nor between social interaction and general BM processing. That is because the ability to process global BM cues is greatly affected by environment and general cognition functions[19].

BM perception is considered a multi-level phenomenon[51-53]. At least in part, processing information of local BM and global BM are different[16,19]. Our results also demonstrate such a dissociation. Local motion processing is stable with age and not susceptible to attention and IQ, which shows a phylogenetically highly preserved mechanism[20,21,54,55] and benefits of life detection[22]. On the contrary, a development

356 tendency seems to exist in global BM processing that tends to be improved with age.
357 A previous study indicated BM perception was enhanced with age in TD children[56].
358 This variation is also observed in children with ASD, and some developmental
359 overlaps were found in the ability to process visual motion information[57].
360 Performance of BM processing within ASD becomes more aligned with TD children,
361 and the discrepancy between the two groups alleviates with the increase in age[32].
362 With regard to ADHD, deficits of social cognition are likely to improve with age in
363 most individuals [5]. Our study further verified this point in BM perception. It is worth
364 noting that the ability of global BM processing positively correlated with the
365 performance of processing general BM cues, i.e., children with ADHD are apt to
366 catch global BM cues to judge the facing direction of the walker when displayed with
367 local and global BM cues, which correspond to a hierarchical model[51]. Once a living
368 creature is detected, an agent (i.e., is it a human?) can be recognized by a coherent,
369 articulated body structure perceptually organized from its motions (i.e., local BM
370 cues)[58], which is a top-down processing and probably requires attention[28,59],
371 especially in the presence of competing information[29]. In addition, cortical processing
372 of BM is strongly modulated by attention[60]. Therefore, as a disorder characterized by
373 deficits of sustained attention, we found its severity of inattention was negatively
374 related to the performance of BM processing.

375 Interestingly, a compensation strategy was found in children with impaired BM
376 perception. No difficulty of BM recognition was found in ASD individuals with high
377 IQ[61], but children with ASD showed weaker adaptation effects for biological motion
378 than TD children[62]. One possibility is that individuals with high IQ and impaired BM
379 perception can better create or reason reliable strategies used for BM recognition[63,64].
380 The current study supported this assumption. Children with higher IQ, particularly
381 Perceptual Reasoning, have better performance. Because of the effect of attention
382 deficits on Perceptual Reasoning, the performance within ADHD will not become
383 aligned with that in TD children.

384 Overall, our study first revealed two atypical fundamental abilities underlying BM
385 perception in children with ADHD, which showed a clear dissociation. Significantly,
386 anomalous local BM processing predicts impaired social interaction in ADHD.
387 Moreover, these results unraveled the potential contributions of age, IQ and attention

to processing BM information. These findings also shed new light on the direction of future studies, which should explore the performance of more advanced BM processing in children with ADHD, such as emotion and identity recognition in BM tasks. In addition, it is necessary to delineate the profiles for neural processing of biological motion in ADHD. A comparative study is warranted to investigate differences between ADHD and ASD, which is essential for finding the common neuropsychological traits and biomarkers of social cognition impairments.

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Author contributions

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Declaration of interests

The authors declare no competing interest.

Ethics

All procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The Institutional Review Board of the Peking University Sixth Hospital has approved this study (reference number for approval: (2020) Ethics Review No.9).

Date availability

The data analyzed during the study is available after publication at https://osf.io/37p5s/

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Figures

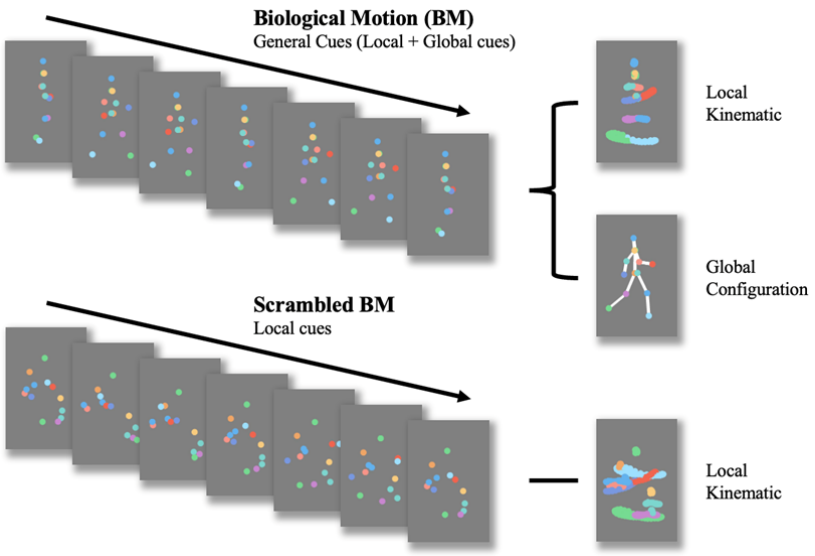

Figure 1. Schematic representation of Biological Motion (BM) and scrambled BM sequence. Intact walker contains information of local kinematics and global configuration. Local kinematics refers to the motion track of each critical joint illustrated by the chromatic dot. Global configuration is composed of the relative locations of each joint. In scrambled BM sequence, global configuration cues have been deprived, but local kinematics have been retained. (Figure reconstructed from Wang et al., 2018[19])

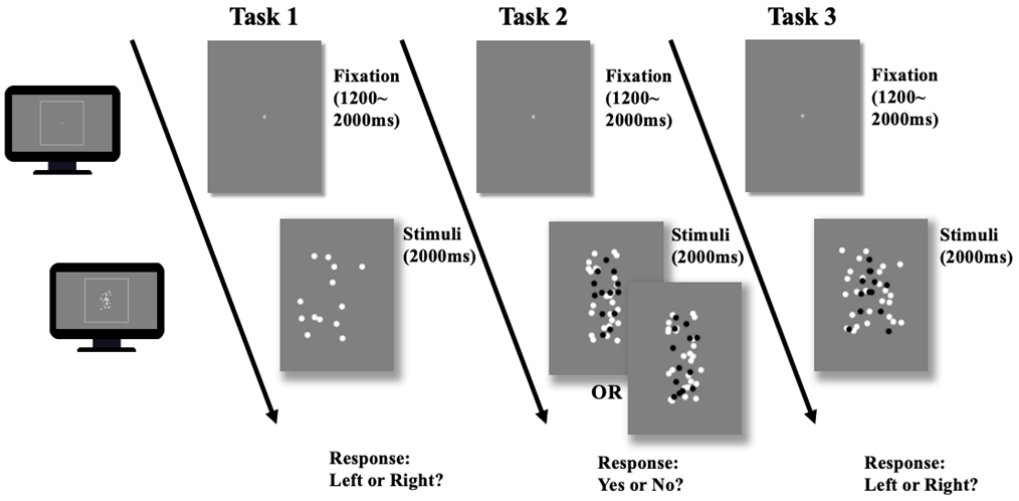

Figure 2. Illustration of the trial sequence. In Task 1 (BM-local), a monitor displayed scrambled BM sequences. Participants only judged the facing direction of the scrambled walker using local BM cues. In Task 2 (BM-global), each trial only showed an intact or scrambled walker (black dots in the figure) embedded in a mask containing local BM cues. Because the two conditions contained the same local cues that were also present in the mask, a participant must rely on global BM cues to judge whether there was an intact walker in the mask. The figure showed one of five possible facing directions of an intact walker (i.e., facing participants). In Task 3 (BM-general), the stimuli sequence consisted of an intact walker (black dots) and a mask containing similar target local cues, and children judged the facing direction of the walker using general BM cues (local + global). Dots in the figure were rendered in black for better illustration and displayed in white in the actual experiments.

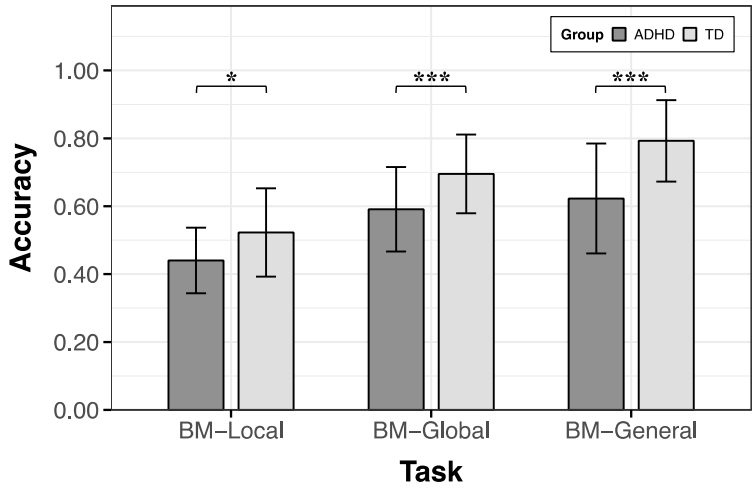

Figure 3. The mean accuracy of the three tasks. Typically developing (TD) children had higher accuracies than children with attention deficit hyperactivity disorder (ADHD) in three tasks in Experiment 1. Error bars show standard errors. *$p < 0.05$; ***$p < 0.001$

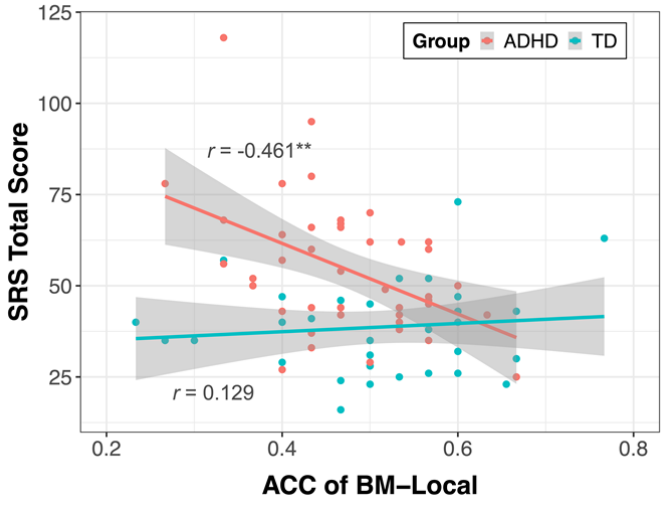

Figure 4. Correlations between the accuracy of Task 1 (BM-Local) and SRS total scores. The correlation between the SRS total score and the ability to process local cues is found in ADHD group. By contrast, this correlation is not found in TD group. The grey shading represents a 95% confidence interval. $^{**}p < 0.01$.

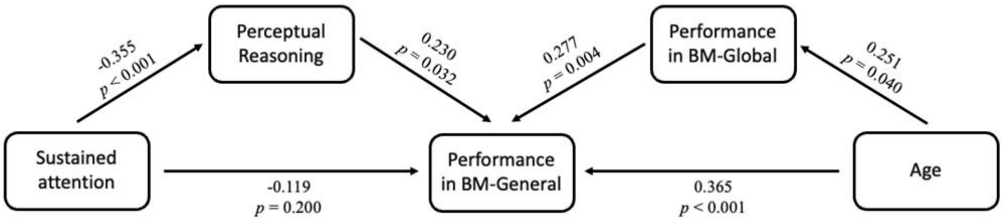

Figure 5. Factors influencing BM perception in ADHD children. Post hoc path analysis confirmed that the effect of sustained attention to performance in BM-General was totally mediated by Perceptual Reasoning, and the ability of global BM processing partly mediated the effect of age on performance in BM-General.

Tables

Table 1. Demographic characteristics of TD and ADHD groups

	Experiment 1		*p* value	Experiment 2		*p* value
	TD	ADHD		TD	ADHD	

Sample	36	39		33	42	
Age (years)	9.08±2.18	9.88±2.23	0.126	8.75±1.94	9.34±1.89	0.191
Gender ratio (% male)	38.89%	71.79%	0.004	42.42%	64.28%	0.059

Table 2. The correlation between the ability of local BM processing and subdimensions of social ability in ADHD children.

	Correlation coefficient (r)	*p* value
Social awareness	-0.333	0.031
Social cognition,	-0.416	0.006
Social communication	-0.381	0.013
Social motivation	-0.406	0.008
Autistic mannerisms	-0.245	0.117
Total score	-0.461	0.002