Biological Psychology 190 (2024) 108820

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Top-down biological motion perception does not differ between adults scoring high versus low on autism traits

Danna Oomen [a,b,c,*], Jan R. Wiersema [a,b], Guido Orgs [d], Emiel Cracco [a,b]

[a] Department of Experimental Clinical and Health Psychology, Ghent University, Belgium
[b] EXPLORA, Ghent University, Belgium
[c] Institute for Management and Organization, Leuphana University, Germany
[d] Institute of Cognitive Neuroscience, University College London, UK

ARTICLE INFO

Keywords:
EEG frequency tagging
Apparent biological motion
Autism

ABSTRACT

The perception of biological motion is an important social cognitive ability. Models of biological motion perception recognize two processes that contribute to the perception of biological motion: a bottom-up process that binds optic-flow patterns into a coherent percept of biological motion and a top-down process that binds sequences of body-posture 'snapshots' over time into a fluent percept of biological motion. The vast majority of studies on autism and biological motion perception have used point-light figure stimuli, which elicit biological motion perception predominantly via bottom-up processes. Here, we investigated whether autism is associated with deviances in the top-down processing of biological motion. For this, we tested a sample of adults scoring low vs high on autism traits on a recently validated EEG paradigm in which apparent biological motion is combined with frequency tagging (Cracco et al., 2022) to dissociate between two percepts: 1) the representation of individual body postures, and 2) their temporal integration into movements. In contrast to our hypothesis, we found no evidence for a diminished temporal body posture integration in the high-scoring group. We did, however, find a group difference that suggests that adults scoring high on autism traits have a visual processing style that focuses more on a single percept (i.e. either body postures or movements, contingent on saliency) compared to adults scoring low on autism traits who instead seemed to represent the two percepts included in the paradigm in a more balanced manner. Although unexpected, this finding aligns well with the autism literature on perceptual stability.

1. Introduction

The ability to process human biological motion, and to extract intentions and affective states from it, plays a major role in social functioning (Pavlova, 2012). Hence, altered processing of biological motion may have serious social consequences. Based on this idea, an important hypothesis for why individuals with a diagnosis of autism spectrum disorder (henceforward 'autism') experience social difficulties (American Psychiatric Association, 2013) is that they process biological motion differently (Moore et al., 1997). Although individual studies investigating this hypothesis have so far yielded mixed results (group differences: e.g. Annaz et al., 2010; Koldewyn et al., 2010; Nackaerts et al., 2012; Price et al., 2012; no group differences: e.g. Cusack et al., 2015; Hubert et al., 2007; Saygin et al., 2010; Wright et al., 2014), three recent meta-analyses summarizing the literature all concluded that biological motion perception is diminished in autism (Federici et al., 2020; Todorova et al., 2019; van der Hallen et al., 2019). However, the three meta-analyses also found high heterogeneity between studies, at least part of which is thought to be due to variations in the type of stimuli used to investigate biological motion perception (Federici et al., 2020; van der Hallen et al., 2019).

So far, most studies investigating biological motion perception in autism have used a class of stimuli referred to as 'point-light figures' (Federici et al., 2020). Point-light figures portray the movements of humans (or other animals) as a constellation of moving dots, typically placed on the major joints of the body (Johansson, 1973). These figures are popular because they are easy to adapt and convey kinematic information devoid of most form distractors (e.g. facial expression and looks). The processing of such point-light figures is known to rely on the integration of optic-flow patterns into a coherent percept of biological

* Correspondence to: Institute for Management and Organization, Leuphana University, Universitätsallee 1, 21335 Lüneburg, Germany.
E-mail address: danna.oomen@leuphana.de (D. Oomen).

https://doi.org/10.1016/j.biopsycho.2024.108820
Received 10 September 2023; Received in revised form 15 May 2024; Accepted 17 May 2024
Available online 28 May 2024

motion (Giese & Poggio, 2003; Johansson, 1973). This is referred to as bottom-up biological motion processing (or as the 'motion' pathway; Giese & Poggio, 2003; Lange & Lappe, 2006). Importantly, however, biological motion perception in real life also involves top-down biological motion processing (also referred to as the 'form' pathway), that is, the binding of body-posture 'snapshots' over time into a fluent movement percept (Giese & Poggio, 2003; Lange & Lappe, 2006). Because point-light figures minimize form information, they do not, or only minimally, engage this type of top-down biological motion processing (Blake & Shiffrar, 2007). In other words, while there is extensive research on bottom-up processing of biological motion in autism, we know only very little about top-down processing of biological motion in this group. This is surprising, because in real life, both types of processing contribute to how biological motion is perceived (Grossman & Blake, 2002). So, if the goal is to gain an understanding of how individuals with autism process biological motion, it is of importance to also investigate top-down processing in autism.

To directly investigate whether top-down processing of biological motion differs in autism, an *apparent* biological motion paradigm can be used. In short, these paradigms represent movements as a sequence of purely static body-postures (Chatterjee et al., 1996; Shiffrar & Freyd, 1990). If these sequences are presented with a time interval between consecutive body postures that is biomechanically possible, this is known to elicit a percept of biological motion in the absence of retinal motion (Orgs & Haggard, 2011). Importantly, given that there is no retinal motion, these paradigms rely predominantly on top-down instead of bottom-up processing (e.g., Orgs et al., 2016). More specifically, it is assumed that apparent biological motion perception is the result of integrating static body postures over time (Giese & Poggio, 2003; Lange & Lappe, 2006).

Recently, a new electroencephalogram (EEG) paradigm was developed to capture this temporal binding process (Cracco et al., 2022). In this paradigm, apparent biological motion (Orgs, Kirsch, et al., 2011, 2013) is combined with frequency tagging (Norcia et al., 2015) by showing sequences of 12 body postures (Fig. 1), either in their natural order (fluent condition) or in a non-fluent order (non-fluent condition). Importantly, the sequences are symmetrical at the midpoint, which results in three frequencies of interest: one coupled to image presentation (base rate), one coupled to the symmetrical turning point in the sequence (half cycle; every 6th image), and one coupled to the repetition of the sequence (full cycle; every 12th image). Critically, fluent and non-fluent sequences generate a different primary percept. In fluent sequences, the primary percept is a series of cyclical movements centred around the half cycle point. Instead, in non-fluent sequences, it is a series of body postures centred around the full cycle point. Stated differently, movements repeat at half cycle rate and body posture sequences repeat at full cycle rate. As a result, their processing can be dissociated at different frequencies of the brain response: the representation of individual body postures is captured at full cycle frequencies, whereas their temporal integration into movements is captured at half cycle frequencies.

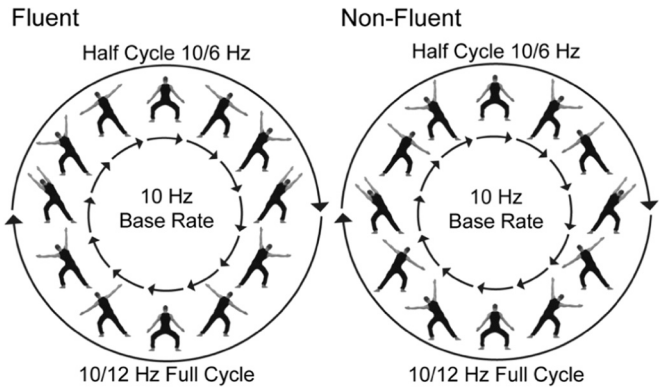

Fig. 1. Stimulus sequence for the fluent and non-fluent condition. Images are presented at a base rate of 10 Hz. Individual postures are repeated at a frequency of 10/12 Hz (full cycle frequency), and movements are completed at a frequency of 10/6 (half cycle frequency).
Figure adapted from Cracco et al. (2022; published under a CC BY license).

With this paradigm, Cracco et al. (2022) indeed found that brain responses at half cycle frequencies were stronger when the postures were ordered to form a fluent movement (fluent > non-fluent condition), whereas brain responses at full cycle frequencies were stronger when they were not (non-fluent > fluent condition; see also Cracco et al., 2023). Here, we applied the apparent biological motion task of Cracco et al. (2022) to investigate if temporal integration of body postures into movements differs between individuals scoring high vs low on autism traits. Autism traits are continuously distributed in the population (Abu-Akel et al., 2019) and previous research has shown that such a dimensional approach in the neurotypical population can give valuable insights into autism and its traits (e.g. Nijhof et al., 2017). If top-down biological motion perception is diminished in autism, one would expect the high-scoring group to show diminished temporal integration of body postures into movements. In other words, to show a reduced effect of movement fluency on half cycle responses but not on full cycle responses.

2. Methods

2.1. Participants

All participants had normal or corrected-to-normal vision, were proficient in Dutch, reported no known neurological condition, had not sought professional help for a mental health problem in the last 6 months before participation, and scored low (≤ 2) or high (≥ 6) on the autism-spectrum quotient-10 (AQ-10; Allison et al., 2012). The AQ-10 is a brief screening tool for ASD that contains 10 items (i.e. the two items with the greatest discriminatory power in each of the five subscales of the full AQ) with a recommended cut-off of 6 for clinical screening purposes. Participants were recruited via an online pre-screening questionnaire in which we assessed the inclusion criteria. A total of 1171 persons filled out the questionnaire, of whom 477 scored low and 84 scored high on the AQ-10. The percentage of persons that scored high on the AQ-10 is in line with previous research (current sample: ~7 %; Waldren et al., 2022: ~8 %). Of those 84 people, 42 met the other inclusion criteria and agreed to go through with participation. For the low-scoring group, we matched the age, sex, and number of participants with those of the high-scoring participants. Three participants were excluded due to technical issues, and 10 participants due to bad signal quality[1] (> 8 electrodes requiring interpolation), resulting in a final sample of 69 participants (34 low-scoring, 35 high-scoring participants). Our sample size was based on practical considerations. That is, we invited everyone in our participant pool that scored high on the AQ-10 and met the other inclusion criteria. A post-hoc sensitivity analysis for the hypothesized 3-way interaction indicates that our sample size allowed for the detection of medium-sized effects ($d = 0.40$). After exclusion, groups did not differ in age, sex, or years of education (See Table 1). None of the participants reported having an actual diagnosis of autism. The experimental protocol was approved by the local ethics committee of the Faculty of Psychology and Educational Sciences of Ghent University (EC/2019/32), and informed consents were obtained from all participants prior to the study. The participants were compensated for their time.

[1] The late identification of faulty equipment led to this high number of participants with bad signal quality.

Table 1
Participant characteristics.

	Low-scoring group *M* (*SD*)	High-scoring group *M* (*SD*)	*F*-value (*p*)
Age	22.65 (3.59)	21.46 (2.78)	2.38 (.128)
Sex (# of females)	17	17	n/a
Years of education	15.82 (1.85)	15.57 (2.61)	0.87 (.354)
Full AQ	11.62 (4.2)	22.06 (7.82)	47.34 (<.001)
SRS-A	30.29 (12.36)	60.77 (25.24)	40.19 (<.001)

Note. low-scoring group $n = 34$; high-scoring group: $n = 35$; full AQ = autism-spectrum quotient; SRS-A = social responsiveness scale - adults

2.2. Task and procedure

Participants were seated in an electrically shielded room approximately 80-100 cm from a 24-inch computer monitor with a 60 Hz refresh rate. Before the start of the apparent biological motion task, all participants completed two questionnaires as well as a computer task of 16 min. This task addressed an unrelated research question and is therefore not further reported here. After a break, participants completed the apparent biological motion task of approximately 22 min. This task was presented using PsychoPy3 (Peirce et al., 2019).

The AQ (full version; Baron-Cohen et al., 2001; Hoekstra et al., 2008) and the social responsiveness scale for adults (SRS-A; Constantino, 2002; Noens et al., 2012), two commonly used questionnaires to measure autism traits, were administered at the start of the test sessions to further describe our sample. As expected, both the AQ and SRS-A scores differed significantly between groups (see Table 1) and correlated with the AQ-10 score (AQ: $r_s = .71$, $p < .001$; SRS-A: $r_s = .70$, $p < .001$).

The apparent biological motion task was nearly identical to the one described by Cracco et al. (2022). Participants were presented with repeating sequences of 12 images (12° × 12°) on a grey background, depicting a dancer in 12 successive whole-body postures (see Orgs, Hagura, et al., 2013, for details on how the stimuli were created). In the fluent condition, the body postures were ordered to produce a fluent movement percept. In the non-fluent condition, the same images were reordered to produce maximal visual displacement between body postures (see Fig. 1). For both conditions, sequences were symmetrical at the midpoint, leading to three frequency responses coupled to distinct features of stimulus presentation: one coupled to image presentation of 10 Hz (base rate), one coupled to the symmetrical turning point in the sequence (half cycle., every 6th image: 10 Hz/6 = 1.67 Hz), and one coupled to the repetition of the image sequence (full cycle, every 12th image: 10 Hz/12 = 0.83 Hz). Crucially, in the fluent condition, the half cycle point is linked to movement completion from side-to-side and movement processing should therefore result in stronger half cycle responses. In contrast, the full cycle point is coupled to the completion of the full body sequence and processing body postures should therefore result in stronger full cycle responses instead.

The two conditions were presented 5 times in randomized blocks. A block consisted of a 120 s video with a 10 s fade in (0–100 %) and a 10 s fade out (100–0 %) to avoid abrupt eye movements and blinks due to the sudden (dis)appearance of stimuli. The videos were created by repeating the 12-image sequence 100 times. To ensure a constant level of attention, participants were instructed to fixate on a grey cross positioned in the centre of the screen, and to press the space bar every time it briefly (400 ms) turned red (which randomly occurred 6–8 times per block; Rossion et al., 2012). Detection rate was high overall (98 % on average). A mixed ANOVA with Fluency (fluent, non-fluent) as within-subject factor and Group (low, high) as between subject factor revealed no main or interaction effects on detection rate (all $ps \geq .079$). The task started with a practice block, for which we used the random condition of Cracco et al. (2022), in which the body postures were presented at random. This control condition only elicits a base rate response as neither postures nor movements repeat predictably when images are presented at random. As Cracco et al. (2022) already demonstrated this, we did not include the random condition in the actual task. However, inspection of the practice block data confirmed that the control condition did indeed only elicit a response at base rate (See Supplementary Material). See Supplementary Materials for short clips of all stimuli conditions.

2.3. EEG recording and pre-processing

EEG was continuously recorded from 64 scalp sites using a sampling rate of 1000 Hz, an ActiCHamp amplifier (Brain Products, Enschede, The Netherlands), and BrainVisionRecorder software (version 1.21.0304, Brain Products, Gilching, Germany). Ag/AgCI active electrodes were positioned according to the extended 10–20 international system. During EEG recording, all channels were referenced to Fz. Horizontal EOG was recorded with FT9 and FT10 electrodes embedded in the cap. Vertical electro-oculogram (EOG) was recorded with additional bipolar AG/AgCI sintered ring electrodes placed above and below the left eye.

Off-line processing of the EEG signal was done using Letswave 6 (https://www.letswave.org/) and followed the procedure of Cracco et al. (2022). First, we applied a fourth-order Butterworth band-pass filter (0.1 Hz - 100 Hz), after which we segmented the data to obtain epochs extending from 2 s before to 122 s after the stimulus onset. Next, ocular artefacts were removed with an independent component analysis (ICA) on the merged segmented data using the Runica algorithm and a square matrix. For each participant, ICs were inspected visually and the ICs related to eye blinks were removed manually. After ICA, we interpolated noisy or faulty electrodes using data from the three closest neighbouring electrodes. The signal was then re-referenced to an average reference. After re-referencing, the segments were cropped to cut out the fade in and fade out periods. This resulted in segments of 96 s and caused the duration of a single segment to be a multiple of the duration of a single sequence (1.2 s), thereby ensuring that the frequencies of interest were captured by a single frequency bin. Finally, trials were averaged per condition and subsequently a Fast Fourier Transform (FFT) was applied to transform the data of each electrode to normalized (divided by N/2) amplitudes in the frequency domain.

2.4. Analysis

For the statistical analysis, we computed the signal to noise-subtracted amplitudes (SNS) at each frequency bin by subtracting the average voltage amplitude of the 20 neighbouring bins as baseline (10 on each side, excluding the immediate adjacent bin). This was done for the three neural responses separately (i.e., base rate, full cycle, and half cycle). Based on the study by Cracco et al. (2022), the SNS for the base rate response was calculated as the sum of the harmonics at 10 Hz, 20 Hz, 30 Hz, 40 Hz, 60 Hz, 70 Hz, 80 Hz, and 90 Hz, the full cycle response was calculated as the sum of the harmonics at 0.83 Hz, 2.50 Hz, 4.17 Hz, 5.83 Hz, 7.50 Hz, 9.17 Hz, 10.83 Hz, 12.5 Hz, 14.17 Hz, and 15.83 Hz, and the half cycle response was calculated as the sum of the harmonics at 1.67 Hz, 3.33 Hz, 5.00 Hz, 6.67 Hz, 8.33 Hz, 11.67 Hz, 13.33 Hz, 15.00 Hz, 16.67 Hz, and 18.33 Hz. Note that only the odd harmonics of the full cycle response were included to avoid overlap with the half cycle response, that 10 Hz was excluded for the half cycle response to avoid overlap with the base rate response, and that 50 Hz and 100 Hz were excluded in the base rate response to exclude line noise.

Based on the study by Cracco et al. (2022), we included the SNS data of 4 clusters in our statistical analyses: a left posterior (PO3, PO7 O1), middle posterior (Poz, Oz), right posterior (PO4, PO8, O2), and a frontocentral cluster (FC1, FCz, FC2). Note that the electrodes included in each cluster were identical to the ones used by Cracco et al. (2022), with the exception that we did not include Iz in the middle posterior cluster, because our electrode setup did not record this electrode site.

On the SNS data, we performed separate mixed design ANOVAs for

the base rate (10 Hz), full cycle (10/12 Hz), and half cycle (10/6 Hz) responses, using Condition (fluent, non-fluent) and Region (left posterior, middle posterior, right posterior, or middle central) as within-subject factors, and Group (low, high) as between-subject factor. Whenever violations of sphericity occurred, the ANOVA degrees of freedom were adjusted according to the Greenhouse-Geisser formula. Significant interactions and main effects of region were followed up by two-tailed *t*-tests. T-values are reported as absolute values.

3. Results

3.1. Base rate (10 Hz)

Images are presented at the base rate of 10 Hz. The base rate therefore captures the processing of images or low-level visual processes associated with the image transitions (e.g., contrast change; Cracco et al., 2022, 2023). As the visual change from image to image is strongest in the non-fluent condition, the base rate response should be strongest for the non-fluent condition. The base rate analysis revealed a main effect of Condition, $F(1, 67) = 10.36$, $p = .002$, $\eta p^2 = .13$, a main effect of Region, $F(2.51, 168.14) = 120.07$, $p < .001$, $\eta p^2 = .64$, and a Condition × Region interaction, $F(2.69, 180.46) = 6.21$, $p = .001$, $\eta p^2 = .09$. There was no main effect of Group, nor interaction effects with Group, all $ps \geq .292$.

As expected, the main effect of Condition indicated that the base rate response was stronger in the non-fluent condition ($M = 2.06$, $SD = 0.87$) than in the fluent condition ($M = 1.89$, $SD = 0.85$), $d_z = 0.39$, 95 % CI [0.14, 0.63]. The main effect of Region revealed that the base rate response was stronger in the three posterior regions (left $M = 2.11$, $SD = 0.98$; middle $M = 2.51$, $SD = 1.26$; right $M = 2.59$, $SD = 1.19$) than in the central region ($M = 0.71$; $SD = 0.36$), all $t(68) \geq 15.03$, $p < .001$, $d_z \geq 1.81$, and that the base rate response was stronger in the middle and right posterior region than in the left posterior region, both $t(68) \geq 3.58$, $p \leq .001$. However, no difference was found between the middle posterior region and the right posterior region $t(68) = 0.63$, $p = .531$, $d_z = 0.07$, 95 % CI [− 0.16, 0.31].

The Condition × Region interaction showed that the effect of fluency was present in the left and right posterior regions (non-fluent left: $M = 2.21$, $SD = 1.05$; fluent left: $M = 2.01$, $SD = 0.99$; non-fluent right: $M = 2.75$, $SD = 1.27$; fluent right: $M = 2.43$,$SD = 1.20$), both $t(68) \geq 3.18$, $p \leq .002$, $d_z \geq 0.38$, and to a lesser extent in the central region (non-fluent: $M = 0.73$, $SD = 0.39$; fluent: $M = 0.68$, $SD = 0.37$), $t(68) \geq 2.00$, $p = .050$, $d_z = 0.24$, 95 % CI [3.74×10^4, 0.48], but not in the middle posterior region, $t(68) = 1.18$, $p = .244$, $d_z = 0.14$, 95 % CI [− 0.10, 0.38].

3.2. Full cycle rate (10/12 Hz)

Individual postures are repeated at the full cycle rate. The full cycle rate therefore primarily captures body perception. As the primary percept in the non-fluent condition is a repeating posture sequence, the full cycle response should be strongest for the non-fluent condition (Cracco et al., 2022, 2023). The full cycle analysis revealed a main effect of Condition $F(1, 67) = 52.86$, $p < .001$, $\eta p^2 = .44$, a main effect of Region, $F(2.65, 177.74) = 181.57$, $p < .001$, $\eta p^2 = .73$, a Region × Condition effect, $F(2.46, 164.58) = 16.93$, $p < .001$, $\eta p^2 = .20$, and a Condition × Group effect, $F(1, 67) = 4.27$, $p = .043$, $\eta p^2 = .06$. There was no main effect of Group or any other interaction effects, all $ps \geq .547$.

As expected, the main effect of Condition indicated that the full cycle response was stronger in the non-fluent ($M = 1.67$, $SD = 0.62$) than in the fluent condition ($M = 1.29$, $SD = 0.50$), $d_z = 0.86$, 95 % CI [0.85, 1.13]. The main effect of Region showed that the response was stronger in the two lateral posterior regions (left $M = 2.08$, $SD = 0.88$; right $M = 2.20$,$SD = 0.88$) than in the middle posterior region ($M = 1.33$, $SD = 0.63$), both $t(68) \geq 8.76$, $p \leq .001$, $d_z \geq 1.05$, and stronger in the three posterior regions than in the central region ($M = 0.30$, $SD = 0.14$), all $t(68) \geq 14.65$, $p \leq .001$ $d_z \geq 1.76$. However, no difference was found between the left and right posterior regions, $t(68) = 1.20$, $p = .236$, $d_z = 0.14$, 95 % CI [− 0.09, 0.38].

The Condition × Region interaction showed a stronger response in the non-fluent than in the fluent condition at every region, all $t(68) \geq 2.32$, $p \leq .023$, $d_z \geq 0.28$ (for means and standard deviations see Supplementary Table 1). The fluency effect was, however, stronger in the posterior regions than the central region, all $t(68) \geq 3.12$, $p \leq .003$, $d_z \geq 0.38$, and stronger in the lateral than in the middle posterior regions, both $t(68) \geq 3.23$, $p \leq .002$, $d_z \geq 0.39$. However, no difference between the two lateral posterior regions was found, $t(68) = 0.42$, $p = .679$, $d_z = 0.05$, 95 % CI [− 0.19, 0.29].

The Condition × Group interaction showed that even though the full cycle response was stronger in the non-fluent condition (low: $M = 1.62$, $SD = 0.61$; high: $M = 1.71$, $SD = 0.64$) than in the fluent condition (low: $M = 1.35$, $SD = 0.57$; high: $M = 1.23$, $SD = 0.43$) for both groups, both $t (\geq 33) \geq 4.04$, $p \leq .001$ $d_z \geq 0.69$, this fluency effect was larger in the high-scoring group ($M = 0.48$, $SD = 0.47$) than in the low-scoring group ($M = 0.27$, $SD = 0.39$).

3.3. Half cycle rate (10/6 Hz)

Movements are completed at the half cycle rate. The half cycle rate therefore primarily captures movement perception. As the primary percept in the fluent condition is a series of movements, the half cycle response should be strongest for the fluent condition (Cracco et al., 2022, 2023). The half cycle analysis revealed a main effect of Condition, $F(1, 67) = 132.89$, $p < .001$, $\eta p^2 = .67$, a main effect of Region, $F(2.34, 157.06) = 196.61$, $p < .001$, $\eta p^2 = .75$, a Condition × Region effect, $F(1, 201) = 21.17$, $p < .001$, $\eta p^2 = .24$, a Condition × Group effect, $F(1, 67) = 5.00$, $p = .029$, $\eta p^2 = .07$ and to a lesser extent a Condition × Region × Group effect, $F(3, 67) = 2.83$, $p = .051$, $\eta p^2 = .04$. There was no main effect of Group or a Region × Group effect, both $ps \geq .662$.

As expected, the main effect of Condition indicated that the half cycle response was stronger in the fluent condition ($M = 2.86$, $SD = 1.02$) than in the non-fluent condition ($M = 1.90$, $SD = 0.76$), $d_z = 1.35$, 95 % CI [− 1.68, − 1.02]. The main effect of Region showed that the half cycle response was stronger in the three posterior regions (left: $M = 2.63$, $SD = 1.01$; middle: $M = 2.99$, $SD = 1.03$; right: $M = 3.03$, $SD = 1.27$) than in the central region ($M = 0.86$, $SD = 0.36$), all $t(68) \geq 17.87$, $\leq .001$, $d_z \geq 2.15$, and that the response was stronger in the middle and right posterior regions than in the left posterior region, both $t(68) \geq 3.23$, $p \leq .002$, $d_z \geq 0.39$. However, no difference was found between the middle posterior region and the right posterior region, $t(68) = 0.36$, $p = .719$, $d_z = 0.04$, 95 % CI [− 0.19, 0.28].

The Condition × Region interaction showed a fluency effect in every region, all $t(68) \geq 8.92$, $p \leq .001$, $d_z \geq 1.07$ (for means and standard deviations see Supplementary Table 2). The effect was, however, stronger in the posterior regions than in the central region, all $t(68) \geq 5.58$, $p < .001$ $d_z \geq 0.67$, and slightly stronger in the right posterior region than in the middle posterior region, $t(68) = 2.01$, $p = .049$, $d_z \geq 0.24$, 95 CI [− 0.48, 0.00]. No other region differences were found, both $ps \geq .164$. Fig. 2 & 3.

The Condition × Group interaction revealed that even though the half cycle response was stronger in the fluent condition (low: $M = 2.79$, $SD = 0.97$; high: $M = 2.92$, $SD = 1.07$) than in the non-fluent condition (low: $M = 2.02$, $SD = 0.77$; high: $M = 1.78$, $SD = 0.73$) for both groups, both $t \geq 6.66$, $p < .001$, $d_z \geq 1.14$, this fluency effect was larger in the high-scoring group ($M = 1.14$, $SD = 0.70$) than in the low-scoring group ($M = 0.77$, $SD = 0.68$).

Finally, the Region × Condition × Group indicated that this larger fluency effect for the high vs the low-scoring group was restricted to the middle and right posterior regions, both $t(67) \geq 2.19$, $p < .032$, $d = 0.53$ (for means and standard deviations see Supplementary Table 3).

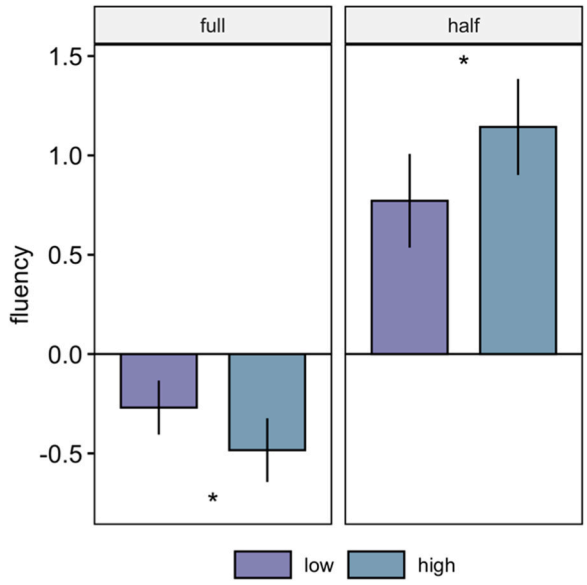

Fig. 2. Fluency effects (fluent – non-fluent) for the two groups (low-scoring, high-scoring) and the two cycle responses (full, half) separately. Error bars represent between-subject 95 % CI's.

4. Discussion

The perception of biological motion is an important social-cognitive ability. It has been hypothesised that autism is associated with altered biological motion perception, and that this difference contributes to social difficulties (Kaiser & Pelphrey, 2012; Moore et al., 1997; Pavlova, 2012). In line with this hypothesis, three independent meta-analyses recently confirmed that biological motion perception in autism is diminished (Federici et al., 2020; Todorova et al., 2019; van der Hallen et al., 2019). Two processes are involved in the perception of real-life biological motion (Grossman & Blake, 2002): a bottom-up process that binds optic-flow patterns into a coherent percept of biological motion and a top-down process that binds sequences of body-posture 'snapshots' over time into a fluent percept of biological motion (Giese & Poggio, 2003; Lange & Lappe, 2006). In this regard it is important to note that, so far, research in autism has focused on bottom-up biological motion perception, with no direct investigation of top-down processing in autism.

To address the hypothesis of an autism-related deviance in top-down biological motion perception, we used a recently validated EEG frequency tagging paradigm (Cracco et al., 2022, 2023) to measure apparent biological motion perception in a sample of adults scoring low vs high on autism traits (Cracco et al., 2022). We replicated the findings of Cracco et al. (2022). That is, we found a stronger brain response for fluent sequences at the frequency that primarily captures movement processing (i.e. half cycle), and a stronger brain response for non-fluent sequences at the frequency that primarily captures body posture processing (i.e. full cycle). However, we found no support for our autism-related hypothesis, as we did not find a specific reduction in the effect of movement fluency on half cycle responses. Hence, we found no evidence for a diminished temporal integration of body postures into movements in adults scoring high on autism traits.

This study therefore provides first evidence that top-down processing of biological motion is not different in autism. However, more research is needed to confirm our results as this is the first study that directly tested this type of biological motion processing in autism. Moreover, the current study used a dimensional approach to autism by testing neurotypical participants who scored either high or low on autism traits. Hence, the findings should be replicated in a sample of individuals with an actual diagnosis of autism. To clarify, autism traits are continuously distributed throughout the whole population, with at the extreme end of the continuum a subpopulation of individuals who may receive a diagnosis of autism (Abu-Akel et al., 2019). Previous research has shown that applying a dimensional approach to autism in the neurotypical population can produce relevant insights about autism (Goris et al., 2017, 2021; Grinter et al., 2009; Nijhof et al., 2017; Robertson & Simmons, 2013; Stewart & Austin, 2009; Walter et al., 2009), Nevertheless, we cannot exclude the possibility that a diminished integration of body postures into movements is instead a categorical characteristic of autism that only emerges in individuals with a formal diagnosis of autism. Therefore, the current study needs to be followed-up by research in clinical samples.

While the results of our study did not support our hypothesis of autism-related diminished top-down processing of biological motion, we observed an interesting group effect. Specifically, we found that the group that scored high on autism traits showed a stronger fluency effect on both the half (fluent > non-fluent) and full cycle (non-fluent > fluent) response. This effect could be interpreted as enhanced temporal integration of body postures into movements in individuals that score relatively high on autism-traits – the opposite of what was expected. Importantly however, because the greater fluency effect was not specific to the half cycle response but was also there for the full cycle response, this interpretation would further imply that the high-scoring group showed enhanced body-posture perception as well. Another perhaps more parsimonious explanation is that there is a more general perceptual difference between individuals who score high vs low on autism traits. To clarify, the image sequences used in the current study could be perceived in two ways: as a sequence of body postures (repeating at full cycle) or as a sequence of movements (repeating at half cycle). Crucially, by manipulating fluency, we could make one percept more salient than the other (i.e., the half cycle percept in the fluent condition and the full cycle percept in the non-fluent condition). Therefore, a parsimonious explanation for the finding that both the half cycle and the full cycle responses were more sensitive to fluency in the high-scoring group is that this group was more influenced by perceptual saliency. While speculative, this potentially indicates that individuals scoring high on autism traits have a perceptual processing style that focuses more on a single percept, in this case the more salient one, whereas individuals scoring low on autism traits have a perceptual processing style in which the two possible percepts (fluent apparent movement or sequence of static body postures) are less clearly dissociated from each other.

This perceptual processing style found in our group scoring high on autism traits aligns well with the autism literature on perceptual stability and rigidity. Previous studies have shown that autism is related to a perceptual processing style that is 'overly' stable (Watanabe et al., 2019). Studies on multistable perception have for example used ambiguous figures (e.g. Necker cubes) that can result in two or more equally possible percepts and create spontaneous perception reversals (Long et al., 1951). Autism studies have found fewer such reversals in adults and children with autism compared to adults and children without autism (Kornmeier et al., 2017; Sobel et al., 2005), with some participants with autism reporting no reversals at all (Kornmeier et al., 2017). Similarly, Watanabe et al. (2019) also reported less reversals in adults with autism compared to adults without autism using bistable structure-from-motion stimuli (i.e. a field of moving dots that can be seen as a sphere that rotates clockwise or counterclockwise). Binocular rivalry studies, which show different images to each eye, also found less reversals in autism (Freyberg et al., 2015; Robertson & Kravitz, Freyberg, et al., 2013). Furthermore, Allen and Chambers (2011) reported perceptual rigidity in the way adolescents with autism mentally represent ambiguous figures. More specifically, using a drawing task, they showed that drawings by adolescents with autism were less influenced by contextual biasing (a label of one of two percepts) compared to a matched control group. Our results may thus be explained by this broader phenomenon of perceptual stability known in autism, as opposed to an explanation specific to biological motion perception. On

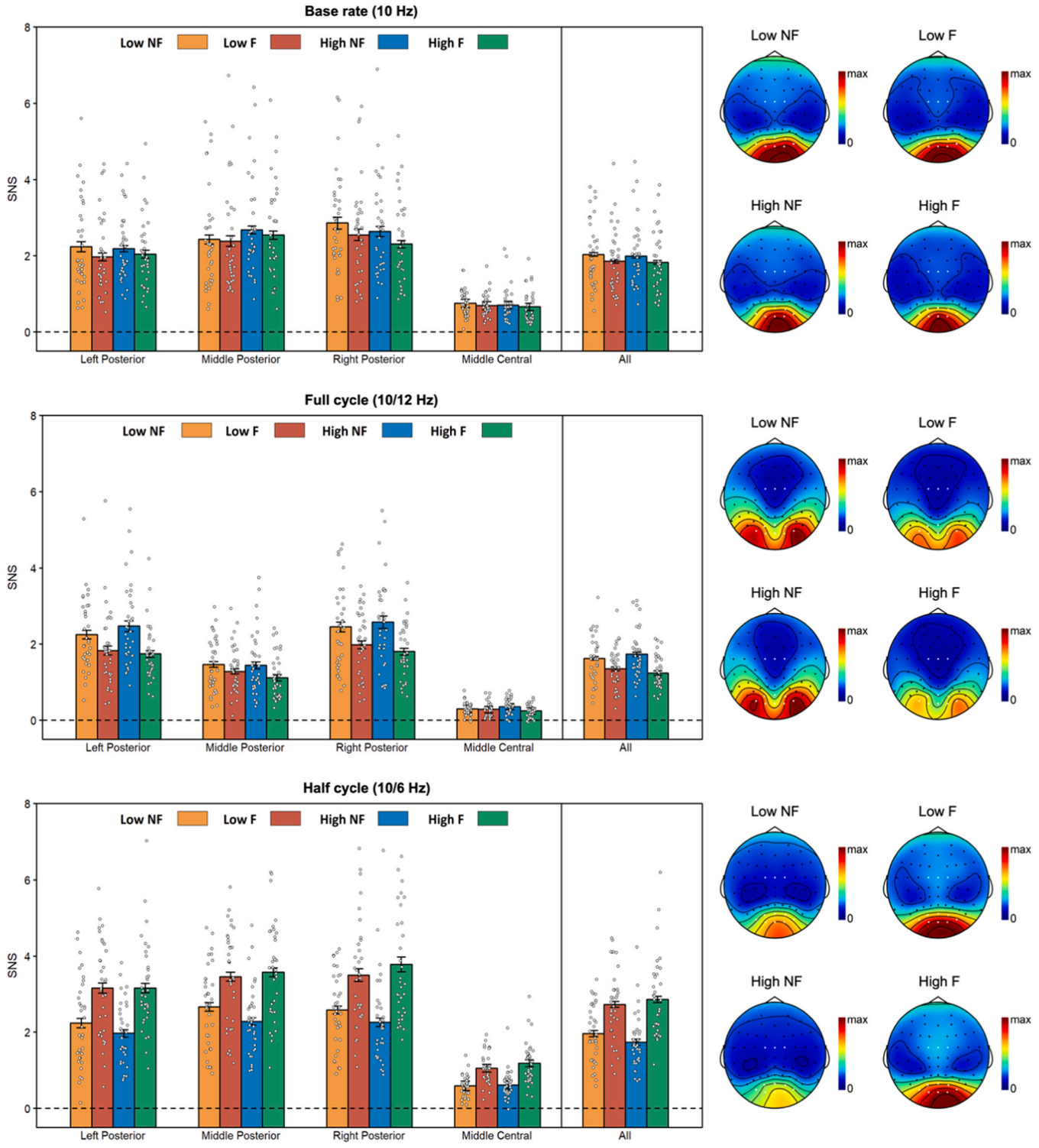

Fig. 3. Noise-subtracted amplitudes (SNS) per group for the two conditions and separately for each region cluster, together with their topographies; Low = low-scoring group, High = high-scoring group, NF = non-fluent, F = fluent. Error bars are standard errors of the mean corrected for within-subject design according to Morey (2008). Topographies are scaled from 0 to the maximum amplitude across conditions for the respective response.

this view, people scoring high on autism traits perceive *either* fluent movement *or* a sequence of body postures, while people scoring low on autism are more like to perceive both percepts at the same time, or – alternatively – perceptually alternate between them over the time course of an experimental trial. The bias in the high-scoring group for the most salient percept as observed in our study, is also in line with a recent study that showed that the often observed altered local/global processing in autism may not be due to a stronger local processing over global processing bias but that differences in local/global processing in autism are driven by exaggerated salience effects (Baisa et al., 2021).

A limitation of the current study is that, in order to minimize the duration of the task, we did not include a non-human condition to control for animacy. However, a recent study by Cracco et al. (2023) that used the same paradigm with both a human (animate) and corkscrew

(non-animate) condition found that movement processing did not depend on animacy. This is consistent with previous work on the bottom-up processing of biological motion (Jastorff et al., 2006) and with theoretical models of biological motion perception (Giese & Poggio, 2003; Lange & Lappe, 2006). Moreover, as outlined above, our autism-related findings are best explained by the broader phenomenon of perceptual stability which applies to the visual perception of both animate and inanimate stimuli. Nonetheless, future studies on biological motion perception in this area might want to add such a control condition.

Two additional limitations relate to the sample. Firstly, the findings of the current study are limited to neurotypical individuals without an actual diagnosis of autism. Hence, future research is warranted to investigate whether the current findings hold in participants with an official diagnosis of autism. Secondly, a post-hoc sensitivity analysis indicated that with our sample size, only effect sizes larger than $d = 0.40$ could be detected. Our findings are therefore limited to effect sizes no smaller than this magnitude, and so it remains possible that we were unable to detect some smaller effect sizes. However, most importantly, we were able to detect the hypothesized 3-way interaction (although the direction of the effect was not in line with our hypothesis). Furthermore, the final sample size is relatively large compared to many previous EEG studies on autism (e.g., Amodeo et al., 2024; Goris et al., 2022, 2018; Nijhof et al., 2018, 2024; Oomen et al., 2022, 2023), larger than those in EEG studies on autism and biological motion perception (see meta-analysis: Todorova et al., 2019), and larger than previous studies using the same paradigm (Cracco et al., 2022, 2023).

To conclude, we replicated the original study by Cracco et al. (2022), and as such validated this paradigm in our sample. That is, we found stronger brain responses for fluent sequences at the frequency that primarily captures movement processing (half cycle), and for non-fluent sequences at the frequency that primarily captures body posture processing (full cycle). However, there was no reduced effect of movement fluency on half cycle responses in the group that scored high on autism traits, so we did not find evidence for diminished top-down processing of biological motion in adults who score high vs. low on autism traits. Instead, we found that the group that scored high on autism traits showed a stronger fluency effect on both half and full cycle responses. In other words, we found that adults scoring high on autism traits have a more stable perceptual processing style, or a bias to process the more salient percept. This processing style is likely not specific to biological motion perception and therefore points towards a more general perceptual difference that is not necessarily tied to social cognition. However, as this was the first study investigating top-down biological motion perception in the context of autism, further research with different paradigms and preferably with a sample of individuals that have a confirmed autism diagnosis, is warranted before firm conclusions can be drawn.

CRediT authorship contribution statement

Emiel Cracco: Writing – review & editing, Visualization, Supervision, Software, Formal analysis, Conceptualization. **Jan R. Wiersema:** Writing – review & editing, Supervision, Conceptualization. **Guido Orgs:** Writing – review & editing, Resources. **Danna Oomen:** Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

Nothing to disclose.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgements

The authors would like to thank all participants for their contribution as well as Anne de Groote and Hannah de Laet for their assistance with data collection, and their help with participant recruitment. DO was supported by the Special Research Fund of Ghent University (BOF18/DOC/348). GO received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 864420 - Neurolive). EC was supported by a postdoctoral fellowship awarded by the Research Foundation Flanders (12U0322N).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.biopsycho.2024.108820.

References

Abu-Akel, A., Allison, C., Baron-Cohen, S., & Heinke, D. (2019). The distribution of autistic traits across the autism spectrum: Evidence for discontinuous dimensional subpopulations underlying the autism continuum. *Molecular Autism, 10*(1), 1–13. https://doi.org/10.1186/S13229-019-0275-3

Allen, M. L., & Chambers, A. (2011). Implicit and explicit understanding of ambiguous figures by adolescents with autism spectrum disorder. *Autism: The International Journal of Research and Practice, 15*(4), 457–472. https://doi.org/10.1177/1362361310393364

Allison, C., Auyeung, B., & Baron-Cohen, S. (2012). Toward brief "red flags" for autism screening: The short Autism Spectrum Quotient and the short Quantitative Checklist in 1,000 cases and 3,000 controls. *Journal of the American Academy of Child and Adolescent Psychiatry, 51*(2), 202–212.e7. https://doi.org/10.1016/j.jaac.2011.11.003

American Psychiatric Association. (2013). DSM-5 Diagnostic Classification. In Diagnostic and Statistical Manual of Mental Disorders. https://doi.org/10.1176/appi.books.9780890425596.x00diagnosticclassification.

Amodeo, L., Goris, J., Nijhof, A. D., & Wiersema, J. R. (2024). Electrophysiological correlates of self-related processing in adults with autism. *Cognitive, Affective & Behavioral Neuroscience*, 1–17. https://doi.org/10.3758/s13415-024-01157-0

Annaz, D., Remington, A., Milne, E., Coleman, M., Campbell, R., Thomas, M. S. C., & Swettenham, J. (2010). Development of motion processing in children with autism. *Developmental Science, 13*(6), 826–838. https://doi.org/10.1111/J.1467-7687.2009.00939.X

Baisa, A., Mevorach, C., & Shalev, L. (2021). Hierarchical processing in ASD is driven by exaggerated salience effects, not local bias. *Journal of Autism and Developmental Disorders, 51*, 666–676. https://doi.org/10.1007/s10803-020-04578-1

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5–17. https://doi.org/10.1023/A:1005653411471

Blake, R., & Shiffrar, M. (2007). Perception of human motion. *Annual Review of Psychology, 58*, 47–73. https://doi.org/10.1146/annurev.psych.57.102904.190152

Chatterjee, S. H., Freyd, J. J., & Shiffrar, M. (1996). Configural processing in the perception of apparent biological motion. *Journal of Experimental Psychology: Human Perception and Performance, 22*(4), 916–929. https://doi.org/10.1037/0096-1523.22.4.916

Constantino, J. N. (2002). *The social responsiveness scale*. Western Psychological Services.

Cracco, E., Lee, H., van Belle, G., Quenon, L., Haggard, P., Rossion, B., & Orgs, G. (2022). EEG frequency tagging reveals the integration of form and motion cues into the perception of group movement. *Cerebral Cortex, 32*(13), 2843–2857. https://doi.org/10.1093/CERCOR/BHAB385

Cracco, E., Linthout, T., & Orgs, G. (2023). The role of objecthood and animacy in apparent movement processing. *Social Cognitive and Affective Neuroscience, 18*(1), Article nsad014. https://doi.org/10.1093/scan/nsad014

Cusack, J. P., Williams, J. H. G., & Neri, P. (2015). Action perception is intact in autism spectrum disorder. *The Journal of Neuroscience, 35*(5), 1849. https://doi.org/10.1523/JNEUROSCI.4133-13.2015

Federici, A., Parma, V., Vicovaro, M., Radassao, L., Casartelli, L., & Ronconi, L. (2020). Anomalous perception of biological motion in autism: A conceptual review and meta-analysis. *Scientific Reports, 10*(1), 1–19. https://doi.org/10.1038/s41598-020-61252-3

Freyberg, J., Robertson, C. E., & Baron-Cohen, S. (2015). Reduced perceptual exclusivity during object and grating rivalry in autism. *Journal of Vision, 15*(13), 11. https://doi.org/10.1167/15.13.11

Giese, M. A., & Poggio, T. (2003). Neural mechanisms for the recognition of biological movements. *Nature Reviews Neuroscience, 4*(3), 179–192. https://doi.org/10.1038/nrn1057.

Goris, J., Braem, S., Nijhof, A. D., Rigoni, D., Deschrijver, E., Van de Cruys, S., & Brass, M. (2018). Sensory prediction errors are less modulated by global context in autism spectrum disorder. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 3*(8), 667–674. https://doi.org/10.1016/j.bpsc.2018.02.003

Goris, J., Braem, S., Van Herck, S., Simoens, J., Deschrijver, E., Wiersema, J. R., & Todd, J. (2022). Reduced primacy bias in autism during early sensory processing. *Journal of Neuroscience, 42*(19), 3989–3999. https://doi.org/10.1523/JNEUROSCI.3088-20.2022

Goris, J., Deschrijver, E., Trapp, S., Brass, M., & Braem, S. (2017). Autistic traits in the general population do not correlate with a preference for associative information. *Research in Autism Spectrum Disorders, 33*, 29–38. https://doi.org/10.1016/j.rasd.2016.11.001

Goris, J., Silvetti, M., Verguts, T., Wiersema, J. R., Brass, M., & Braem, S. (2021). Autistic traits are related to worse performance in a volatile reward learning task despite adaptive learning rates. *Autism, 25*(2), 440–451. https://doi.org/10.31234/osf.io/dxt47

Grinter, E. J., Maybery, M. T., Van Beek, P. L., Pellicano, E., Badcock, J. C., & Badcock, D. R. (2009). Global visual processing and self-rated autistic-like traits. *Journal of Autism and Developmental Disorders, 39*(9), 1278–1290. https://doi.org/10.1007/s10803-009-0740-5

Grossman, E. D., & Blake, R. (2002). Brain areas active during visual perception of biological motion. *Neuron, 35*(6), 1167–1175. https://doi.org/10.1016/S0896-6273(02)00897-8

Hoekstra, R. A., Bartels, M., Cath, D. C., & Boomsma, D. I. (2008). Factor structure, reliability and criterion validity of the Autism-Spectrum Quotient (AQ): A study in Dutch population and patient groups. *Journal of Autism and Developmental Disorders, 38*(8), 1555–1566. https://doi.org/10.1007/S10803-008-0538-X

Hubert, B., Wicker, B., Moore, D. G., Monfardini, E., Duverger, H., da Fonséca, D., & Deruelle, C. (2007). Brief report: Recognition of emotional and non-emotional biological motion in individuals with autistic spectrum disorders. *Journal of Autism and Developmental Disorders, 37*(7), 1386–1392. https://doi.org/10.1007/S10803-006-0275-Y

Jastorff, J., Kourtzi, Z., & Giese, M. A. (2006). Learning to discriminate complex movements: Biological versus artificial trajectories. *Journal of Vision, 6*(8), 791–804. https://doi.org/10.1167/6.8.3

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

Koldewyn, K., Whitney, D., & Rivera, S. M. (2010). The psychophysics of visual motion and global form processing in autism. *Brain: A Journal of Neurology, 133*(Pt 2), 599–610. https://doi.org/10.1093/BRAIN/AWP272

Kornmeier, J., Wörner, R., Riedel, A., & van Elst, L. T. (2017). A different view on the Necker cube—Differences in multistable perception dynamics between Asperger and non-Asperger observers. *PLoS ONE, 12*(12), Article e0189197. https://doi.org/10.1371/ JOURNAL.PONE.0189197.

Lange, J., & Lappe, M. (2006). A model of biological motion perception from configural form cues. *The Journal of Neuroscience, 26*(11), 2894. https://doi.org/10.1523/JNEUROSCI.4915-05.2006.

Long, G. M., Toppino, T. C., & Bulletin, P. (1951). Enduring interest in perceptual ambiguity: Alternating views of reversible figures. *Psychological Association, 130*(5), 748–768. https://doi.org/10.1037/0033-2909.130.5.748

Moore, D. G., Hobson, R. P., & Lee, A. (1997). Components of person perception: An investigation with autistic, non-autistic retarded and typically developing children and adolescents. *British Journal of Developmental Psychology, 15*, 4014123. https://doi.org/10.1111/j.2044-835X.1997.tb00738.x.

Nackaerts, E., Wagemans, J., Helsen, W., Swinnen, S. P., Wenderoth, N., & Alaerts, K. (2012). Recognizing biological motion and emotions from point-light displays in autism spectrum disorders. *PLoS One, 7*(9), Article e44473. https://doi.org/10.1371/JOURNAL.PONE.0044473

Nijhof, A., D., Catmur, C., Brewer, R., Coll, M. P., Wiersema, J. R., & Bird, G. (2024). Differences in own-face but not own-name discrimination between autistic and neurotypical adults: A fast periodic visual stimulation-EEG study. *Cortex, 171*, 308–318. https://doi.org/10.1016/j.cortex.2023.10.023

Nijhof, A. D., Brass, M., & Wiersema, J. R. (2017). Spontaneous mentalizing in neurotypicals scoring high versus low on symptomatology of autism spectrum disorder. *Psychiatry Research, 258*, 15–20. https://doi.org/10.1016/j.psychres.2017.09.060

Nijhof, A. D., Dhar, M., Goris, J., Brass, M., & Wiersema, J. R. (2018). Atypical neural responding to hearing one's own name in adults with ASD. *Journal of Abnormal Psychology, 127*(1), 129. https://doi.org/10.1037/abn0000329

Noens, I., de la Marche, W., & Scholte, E. (2012). *Screeningslijst voor autisme espectrumstoornissen*. Hogrefe Uitgevers B.V.

Norcia, A. M., Gregory Appelbaum, L., Ales, J. M., Cottereau, B. R., & Rossion, B. (2015). The steady-state visual evoked potential in vision research: A review. *Journal of Vision, 15*(6), 1–46. https://doi.org/10.1167/15.6.4

Oomen, D., Cracco, E., Brass, M., & Wiersema, J. R. (2023). EEG frequency tagging evidence of intact social interaction recognition in adults with autism. *Autism Research, 16*(6), 1111–1123. https://doi.org/10.1002/aur.2929

Oomen, D., El Kaddouri, R., Brass, M., & Wiersema, J. R. (2022). Neural correlates of own name and own face processing in neurotypical adults scoring low versus high on symptomatology of autism spectrum disorder. *Biological Psychology, 172*, Article 108358. https://doi.org/10.1016/j.biopsycho.2022.108258

Orgs, G., Bestmann, S., Schuur, F., & Haggard, P. (2011). From body form to biological motion: The apparent velocity of human movement biases subjective time. *Psychological Science, 22*(6), 712–717. https://doi.org/10.1177/0956797611406446

Orgs, G., Dovern, A., Hagura, N., Haggard, P., Fink, G. R., & Weiss, P. H. (2016). Constructing visual perception of body movement with the motor cortex. *Cerebral Cortex, 26*(1), 440–449. https://doi.org/10.1093/CERCOR/BHV262

Orgs, G., & Haggard, P. (2011). Temporal binding during apparent movement of the human body. *19*(7), 833–845. https://doi.org/10.1080/13506285.2011.598481

Orgs, G., Hagura, N., & Haggard, P. (2013). Learning to like it: Aesthetic perception of bodies, movements and choreographic structure. *Consciousness and Cognition, 22*(2), 603–612. https://doi.org/10.1016/j.concog.2013.03.010

Orgs, G., Kirsch, L., & Haggard, P. (2013). Time perception during apparent biological motion reflects subjective speed of movement, not objective rate of visual stimulation. *Experimental Brain Research, 227*(2), 223–229. https://doi.org/10.1007/S00221-013-3502-8

Pavlova, M. A. (2012). Biological motion processing as a hallmark of social cognition. *Cerebral Cortex, 22*(5), 981–995. https://doi.org/10.1093/CERCOR/BHR156

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods, 51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Price, K. J., Shiffrar, M., & Kerns, K. A. (2012). Movement perception and movement production in Asperger's Syndrome. *Research in Autism Spectrum Disorders, 6*(1), 391–398. https://doi.org/10.1016/J.RASD.2011.06.013

Robertson, A. E., & Simmons, D. R. (2013). The relationship between sensory sensitivity and autistic traits in the general population. *Journal of Autism and Developmental Disorders, 43*(4), 775–784. https://doi.org/10.1007/s10803-012-1608-7

Robertson, C. E., Kravitz, D. J., Freyberg, J., Baron-Cohen, S., & Baker, C. I. (2013). Slower rate of binocular rivalry in autism. *The Journal of Neuroscience, 33*(43), 16983. https://doi.org/10.1523/JNEUROSCI.0448-13.2013

Rossion, B., Prieto, E. A., Boremanse, A., Kuefner, D., & Van, Belle (2012). A steady-state visual evoked potential approach to individual face perception: Effect of inversion, contrast-reversal and temporal dynamics. *NeuroImage, 63*(3), 1585–1600. https://doi.org/10.1016/j.neuroimage.2012.08.033

Saygin, A. P., Cook, J., & Blakemore, S. J. (2010). Unaffected perceptual thresholds for biological and non-biological form-from-motion perception in autism spectrum conditions. *PLoS One, 5*(10), Article e13491. https://doi.org/10.1371/JOURNAL.PONE. 0013491

Shiffrar, M., & Freyd, J. J. (1990). Apparent motion of the human body. *Psychological Science, 1*(4), 257–264. https://doi.org/10.1111/J.1467-9280.1990.TB00210.X

Sobel, D. M., Capps, L. M., & Gopnik, A. (2005). Ambiguous figure perception and theory of mind understanding in children with autistic spectrum disorders. *British Journal of Developmental Psychology, 23*(2), 159–174. https://doi.org/10.1348/026151004×20694.

Stewart, M. E., & Austin, E. J. (2009). The structure of the Autism-Spectrum Quotient (AQ): Evidence from a student sample in Scotland. *Personality and Individual Differences, 47*, 224–228. https://doi.org/10.1016/j.paid.2009.03.004

Todorova, G. K., Hatton, R. E. M. B., & Pollick, F. E. (2019). Biological motion perception in autism spectrum disorder: a meta-analysis. *Molecular Autism, 10*(1), 1–28. https://doi.org/10.1186/S13229-019-0299-8

van der Hallen, R., Manning, C., Evers, K., & Wagemans, J. (2019). Global motion perception in autism spectrum disorder: A meta-analysis. *Journal of Autism and Developmental Disorders, 49*(12), 4901. https://doi.org/10.1007/S10803-019-04194-8

Waldren, L.H., Livingston, L.A., Clutterbuck, R.A., Callan, M.J., Walton, E., & Shah, P. (2022, February 21). Using Incorrect Cut-Off Values in Autism Screening Tools: The Consequences for Psychological Science. https://doi.org/10.31234/osf.io/x4h7n.

Walter, E., Dassonville, P., & Bochsler, T. M. (2009). A specific autistic trait that modulates visuospatial illusion susceptibility. *Journal of Autism and Developmental Disorders, 39*(2), 339–349. https://doi.org/10.1007/s10803-008-0630-2

Watanabe, T., Lawson, R. P., Walldén, Y. S. E., & Rees, G. (2019). A neuroanatomical substrate linking perceptual stability to cognitive rigidity in autism. *The Journal of Neuroscience, 39*(33), 6540. https://doi.org/10.1523/JNEUROSCI.2831-18.2019

Wright, K., Kelley, E., & Poulin-Dubois, D. (2014). Schematic and realistic biological motion identification in children with high-functioning autism spectrum disorder. *Research in Autism Spectrum Disorders, 8*(10), 1394. https://doi.org/10.1016/ J.RASD.2014.07.005.