# *The integration of head and body cues during the perception of social interactions*

Article

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1    **The Integration of Head and Body Cues during the Perception of Social Interactions**

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26    Tables: 2
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31 **Abstract:** Humans spend a large proportion of time participating in social interactions. The ability to

32 accurately detect and respond to human interactions is vital for social functioning, from early

33 childhood through to older adulthood. This detection ability arguably relies on integrating sensory

34 information from the interactants. Within the visual modality, directional information from a person's

35 eyes, head, and body are integrated to inform where another person is looking and who they are

36 interacting with. To date, social cue integration research has focused largely on the perception of

37 isolated individuals. Across two experiments, we investigated whether observers integrate body

38 information with head information when determining whether two people are interacting, and

39 manipulated frame of reference (one of the interactants facing observer vs. facing away from

40 observer) and the eye-region visibility of the interactant. Results demonstrate that individuals

41 integrate information from the body with head information when perceiving dyadic interactions, and

42 that integration is influenced by the frame of reference and visibility of the eye-region. Interestingly,

43 self-reported autistics traits were associated with a stronger influence of body information on

44 interaction perception, but only when the eye-region was visible. This study investigated the

45 recognition of dyadic interactions using whole-body stimuli while manipulating eye visibility and

46 frame of reference, and provides crucial insights into social cue integration, as well as how autistic

47 traits affect cue integration, during perception of social interactions.

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49 **Keywords:** social interaction, perception, cue integration, autism

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Humans are a profoundly social species and routinely process rich social information in their daily lives. The ability to quickly and accurately perceive individual agents, as well as the interactions and nature of relationships between individuals, is crucial for the successful navigation of our social world. We are quick to identify whether two people who are standing in close proximity to one another are engaged in a social interaction or behaving independently. While research has made significant progress in elucidating the nature of perception of individual agents, research has only recently started to investigate the processes underlying visual recognition of social interactions.

Interestingly, recent research shows that dyads positioned to imply an interaction are recognised more quickly and accurately than dyads facing away from each other (Papeo et al., 2017; Papeo, Goupil, & Soto-Faraco, 2019; Vestner et al., 2019). This search advantage for interacting dyads is suggested to be due to the strong directional cues (e.g. face, nose, feet) present within these arrangements (Vestner et al, 2020). Additionally, interacting individuals are processed in different regions of cortex compared to non-interacting individuals (Isik, Koldewyn, Beeler, & Kanwisher, 2017; Walbrin et al., 2018; Abassi & Papeo, 2020). These recent findings suggest that individuals positioned to imply an interaction are not perceived as two isolated individuals, but as two interacting individuals, and should thus be investigated as such.

In face-to-face social interactions, interacting individuals continuously exchange social signals, such as facial expressions, body gestures, speech, and gaze. Gaze has a dual-function (Canigueral & Hamilton, 2019); it tells us where our interaction partner is looking (Frischen et al., 2007) and what they might be thinking (Baron-Cohen et al., 1997), while also relaying the same information about our gaze behaviour to them. Thus, the ability to accurately judge the direction of another's gaze is crucial in understanding complex and dynamic social environments such as social interactions. Unsurprisingly, humans exhibit a high degree of accuracy in judging the gaze direction

85   of others (e.g. Gibson & Pick, 1963; Symons et al., 2004; Bock et al., 2008), and the human eye is

86   suggested to have evolved to promote this ability (Kobayashi et al., 2001; Kobayashi et al., 1997).

87

88         Although perceiving the direction of another's gaze is crucial in accurately estimating the

89   focus of their attention, accurate gaze estimation requires the integration of various other informative

90   cues in our environments, such as directional information from another person's head (Wollaston,

91   1824; Balsdon & Clifford, 2017) and body (Moors et al., 2015). However, although the primary need

92   for integration of social cues is during social situations that typically involve more than one person,

93   social cue integration research has focused mostly on the visual perception of single individuals.

94   Additionally, the extent to which body information is integrated with head and eye-region information

95   during gaze perception has been investigated to a limited extent.

96

97         Observers quickly and accurately judge the direction of gaze when directional cues of the

98   eyes and head of isolated individuals are aligned (Langton, 2000; Ricciardelli et al., 2008; Seyama &

99   Nagayama, 2005). However, when the eyes and the orientation of the head are misaligned, the

100  integration of these cues introduces biases. For example, when the eyes of a looker are pointing

101  directly towards an observer but the head is turned laterally, perceived gaze direction shifts in the

102  direction opposite the head. This has been termed the overshoot, or repulsive, effect (Langton et al.,

103  2000). This bias may be caused by a change in the amount of visible white sclera on either side of the

104  iris when a person's eyes are fixated while the head rotates, in a similar way to when gaze is averted

105  but the head remains pointing forward (Anstis et al., 1969; Otsuka et al., 2014). To counteract this

106  overshoot effect caused by a change in eye-region information, the towing, or attractive, effect

107  (Maruyama & Endo, 1983) attempts to reduce the error in perceived gaze direction by utilising head

108  information as a direct cue, pulling perceived gaze direction back towards the veridical (Otsuka et al.,

109  2014). The overshoot effect has also been observed for the perception of head orientation in the

110  presence of a misaligned body cue (Moors et al., 2015; Figure 1).

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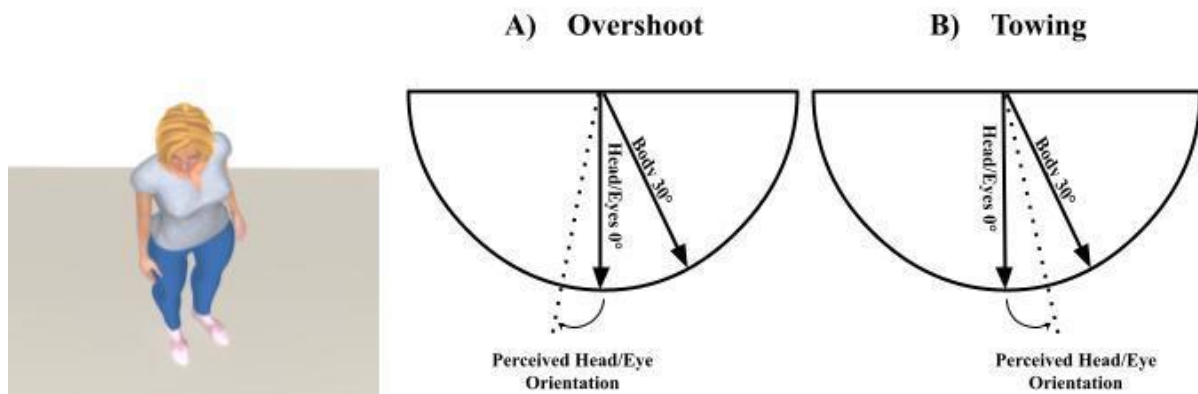
*Figure 1.* An illustration of the (A) overshoot and (B) towing effects (adapted from Moors et al., 2016).

Social cue integration has been shown to vary across different contexts. Participants integrate and weight sensory evidence differently depending on the type of judgement they are making about the gaze of another person (Balsdon & Clifford, 2018). When participants judge the relative direction of another's gaze (i.e. allocentric perspective), a stronger overshoot effect of the head is observed compared to when observers judge whether or not gaze is directed at them (i.e. egocentric perspective).

Additionally, the integration of social cues during gaze perception is influenced by individual differences. For example, individuals with schizophrenia, who show impairments in self-referential gaze perception (Hooker & Park, 2005; Rosse, Kendrick, Wyatt, et al., 1994; Tso, Mui, Taylor, & Deldin, 2012), show no differences in gaze estimation accuracy when judging whether gaze is directed to the left, right, or straight ahead (i.e. making a judgement about the relative direction of gaze; Seymour et al., 2017). Thus, individuals with schizophrenia show differences while judging the direction of gaze in relation to themselves (i.e. egocentric judgement), while they show no such differences when judging the relative direction of gaze (i.e. allocentric judgement). Enhanced self-referential perception of gaze has also been associated with social anxiety symptoms (Harbort et al.,

5

133    2013; Gamer et al., 2011; Schulze, Lobmaier, Arnold, & Renneberg, 2013; Jun et al., 2013; Schulze,

134    Renneberg, & Lobmaier, 2013).

135

136         Further, individuals with Autism Spectrum Conditions (ASC[1]) show differences in social cue

137    integration when viewing images of isolated individuals (Ashwin et al., 2015; Mihalache et al., 2020);

138    autistic observers focus more on body than head information (Ashwin et al., 2015), and utilise

139    information from the eyes less than non-autistic individuals (Mihalache et al., 2020), when judging

140    the direction of an individual's gaze. These findings are potentially explained by their enhanced

141    perception of features at the expense of global processing (Happé, 1999). Increased reliance on one

142    cue, and aberrant integration of cues from the eyes, head, and body when judging gaze direction,

143    could lead to inaccurate gaze perception, leading to difficulties in successfully identifying and

144    responding to social interactions. However, the nature and extent of cue integration during perception

145    of social interactions in autistic individuals is relatively unknown. Individual social cues can be

146    perceived differently if we make judgments about them from a first-person (egocentric) perspective vs

147    from a third-person perspective (Balsdon & Clifford, 2018). Relatedly, it is unclear whether autistic

148    symptoms, which are typically associated with differences in social processing, modulate social cue

149    integration across allocentric and egocentric frame(s) of reference (FoR).

150

151         It remains unknown how cue integration works when social interactions are viewed from

152    third-person perspectives, and how allocentric and egocentric FoR influence judgments of dyadic

153    interactions. Thus, in the first experiment, we sought to investigate whether observers integrate

154    directional cues from the body with head orientation information when judging whether two people

155    are interacting, using well controlled, computer-generated stimuli that systematically vary in head and

156    body orientation. Importantly, we occluded the visibility of the eye-region with dark sunglasses such

157    that any judgements of interaction may be made based on information from the orientation of the head

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[1] We recognise the diversity of views on terminology within the autism community. To reflect this diversity of views, we use the phrase 'individuals with Autism Spectrum Conditions' interchangeably with 'autistic individuals'.

6

158    and body, rather than directly from the eye-region. Similarly to Moors et al. (2015), this study

159    examines how body orientation influences assumed gaze direction. Additionally, we investigated

160    whether cue integration is influenced by FoR (i.e. allocentric vs. egocentric), and whether autistic

161    traits affect the nature of social cue integration during the perception of social interactions.

162

163    **Experiment 1**

164                                         **Methods**

165    **Open Science Statement**
166
167    The study was pre-registered on AsPredicted.org. In line with open science initiatives (Munafo et al.,

168    2017), data and stimuli from this study are freely available online, and we report all data exclusions

169    and measures in the study.

170

171    **Participants**
172
173    Participants were recruited via Amazon's Mechanical Turk and were paid $7.00 for 30-45 minutes of

174    their time. Studies investigating individual differences are likely to find small effect sizes (Schäfer &

175    Schwarz, 2019), thus, to investigate the impact of autistic traits on interaction perception, a sample of

176    N=120 allows us to detect small effect sizes with 80% power.

177

178    As the study was conducted online, participant data were only included in the final dataset if their

179    total attention score was above 75% (attention checks are detailed in the Procedure section); data from

180    a total of N=131 participants were included in the final dataset. However, after applying the exclusion

181    criteria as detailed in the Data Analysis section, N=118 participants remained in the analysis ($M_{age}$ =

182    37.75, SD = 7.65, 60 females). All participants provided written informed consent, and the experiment

183    was approved by the University of Reading, School of Psychology and Clinical Language Sciences

184    Ethics Committee (ethical approval number: 2020-098-BC) and conducted in line with ethical

185    guidelines presented in the 6th (2008) Declaration of Helsinki.

186
187    **Stimuli**

188    Stimuli containing two female avatars presented within three different scenes/conditions were

189    developed using Poser 12 software (Bondware, Inc). Three scenes were developed to represent

190    egocentric and allocentric FoR; Conditions 1 and 3 acted as proxies for an allocentric FoR (n.b. these

191    conditions are identical but horizontally flipped), and Condition 2 acted as a proxy for an egocentric

192    FoR (Figure 2A; see Supplementary Information 2 for further examples of stimuli).

193

194    Within each of the three FoR, the head and body orientation of one of the avatars remained static,

195    while the other's head and body orientation varied systematically. In Condition 1 (allocentric), the

196    static avatar was positioned to the left of the screen with a head and body orientation of 125° relative

197    to the observer, while the moving avatar was positioned centrally in the scene with a neutral head and

198    body position of 305° relative to the observer (n.b. the neutral position of the moving avatar

199    represents the veridical 'interacting' response, as this is where both avatars directly face each other).

200    The head orientation of the moving avatar ranged from -30° left to 30° right of the static avatar in

201    steps of 5°, creating 13 unique head orientations. The body of the moving avatar was oriented either -

202    30° left, 30° right, or directly facing (0°) the static avatar. Although similar to Condition 1, the static

203    avatar in Condition 3 (allocentric) was positioned to the right of the screen (215° relative to the

204    observer; a horizontal flip of Condition 1). The static avatar in Condition 2 (egocentric) was

205    positioned in the centre of the screen and turned 180° relative to the observer so that only the back of

206    their head/body was visible, while the moving avatar's neutral (or veridical interacting) position was

207    directly facing the observer (0°). The camera position (X = 0°, Y = 4°, Z = 41°) was elevated such that

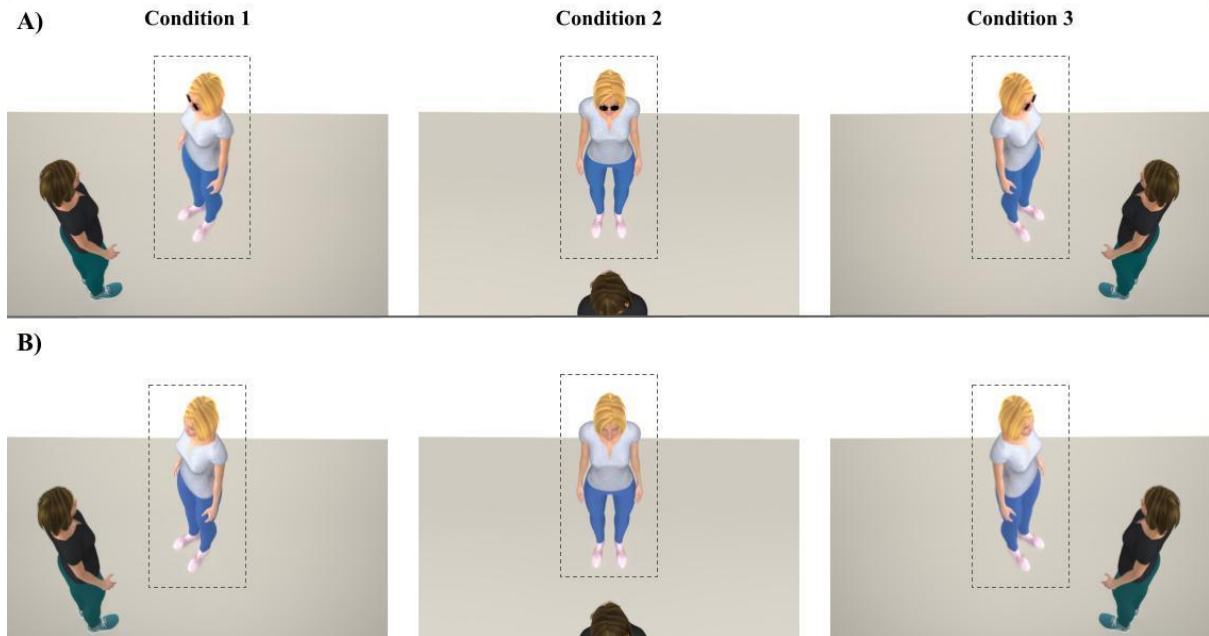208    both avatars would be visible across all three conditions.

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*Figure 2.* Examples of stimuli presented in (A) Experiment 1 and (B) Experiment 2. Stimuli containing dyads in neutral/interacting positions across Condition 1 (allocentric), Condition 2 (egocentric), and Condition 3 (allocentric). The head orientations of the moving avatar (outlined with a dashed rectangle for illustration purposes) varied from -30° to +30° in steps of 5°, and the body was turned -30°, 0°, or +30°.

**Procedure**

The experimental task was hosted on Gorilla Experiment Builder (www.gorilla.sc). Participants were restricted to completing the task from a laptop or desktop computer (64% used the Chrome browser, 5% used Firefox, 4% used Edge, and the browser type was not recorded for 27% of participants). Each trial began with a central fixation cross presented for 500 milliseconds (ms). A blank screen then appeared for 100 ms before a static image of a dyad (image size: 1085 x 822 pixels) was displayed at full resolution for 750 ms. After the presentation of the dyad, participants were asked to respond as to whether or not the dyad was interacting (two-alternative forced choice task; 2AFC). Participants used the 'Y' and 'N' letters on the keyboard to record 'Yes' and 'No' responses respectively; the next trial started after participants made a response. Participants firstly completed 9 practice trials to get acquainted with the task; the practice trials displayed only trials in which the answer to the question

232 'Are these two people interacting?' was clear (e.g. a head oriented -30° presented with a body

233 oriented -30° should be a simple 'No' response, and a head oriented 0° presented with a body oriented

234 0° should be a simple 'Yes' response). Subsequently, with 6 repetitions of each combination of head,

235 body, and FoR, participants completed a total of 702 trials across 6 blocks. Breaks could be taken in

236 between blocks of trials. As the task was completed online, attention checks were presented randomly

237 throughout to ensure participants were engaged with the task. To reduce the likelihood of submission

238 from bots and random responding from participants, we included free-text responses to simple

239 questions (e.g. 'How many characters did you see on the last screen?', 'What is the date today?' or

240 'What is your age?').

241

242 To measure self-reported autistic traits, at the end of the task participants completed the Autism

243 Spectrum Quotient (AQ) questionnaire (Baron-Cohen et al., 2001) ($M = 20.22$, $SD = 8.63$), which also

244 included two catch-questions to reduce the likelihood of participants responding randomly. Only

245 participants who scored above 75% across all attention trials were included in the analyses.

246

247 **Data Analysis**

248 Data from the 2AFC task were pre-processed in MATLAB (version R2015b) in the same way as

249 described in Balsdon and Clifford (2018). The proportion of 'interacting' responses at each head

250 orientation was fit with the difference between two logistic functions (i.e. if participants had been

251 asked to judge the pointing direction of the head of a looker, rather than judge whether a dyad is

252 interacting, one logistic function would be fit to increasing leftward head responses made by the

253 participant as the head of the looker rotates further left, and one would be fit to increasing rightward

254 head responses as the head rotates further right). The peak of the 'interacting' responses (or the head

255 orientation at which the maximum of these functions occurred) was interpreted as the head orientation

256 that maximally signals interaction in the dyad. If the body orientation had no influence on interaction

257 perception, then the head orientation associated with the highest 'interacting' responses should be

258 identical between the leftward and rightward oriented bodies. We could therefore assess whether

259    observers integrate information from the body with information from the head when perceiving

260    interaction by computing an estimate of the influence of body orientation on interaction perception;

261    this was calculated by finding the difference between the head orientation at which the peak of

262    'interacting' responses was observed for the leftward and the rightward oriented bodies, and dividing

263    this difference by two (we assume that cue integration is identical across hemifields) (Palmer et al.,

264    2018; Balsdon et al., 2018). This represents the average extent to which body orientation shifts

265    interaction perception away from that indicated by head orientation alone. If this value is equal to $0°$,

266    then body orientation has no influence on interaction perception. A value greater than $0°$ would

267    suggest that the orientation of the body leads to interaction being perceived in the direction opposite

268    the body (i.e. overshoot/repulsive effect), while a negative value would suggest that interaction is

269    perceived in the same direction as the body (i.e. towing/attractive effect; Figure 1). All subsequent

270    statistical analyses were performed on the measure of the influence of body orientation on interaction

271    perception, henceforth referred to as *Body Influence*.

272

273    Before analysis, participant data were excluded if the peak of the proportion of interacting responses

274    was outside the range of head orientations presented (i.e. greater than $+30°$ or smaller than $-30°$)

275    (Balsdon et al., 2018). Inspection of data from excluded participants revealed that N=5 participants

276    responded only to the orientation of the body and not to the orientation of the head, whilst others

277    appeared to respond randomly, failing to follow experimental instructions (N=8).

278

279    Using the lmerTest package (Kuznetsova et al., 2017) in R (version 4.1.2; R Core Team, 2021) we fit

280    linear mixed-effects models using restricted maximum-likelihood to investigate whether body

281    influence values were predicted by FoR, autistic traits, and their interaction. Participants were entered

282    as random effects, and age and gender were included as fixed-effect covariates (formula: Body

283    Influence ~ FoR * Autistic Traits + Age + Gender + (1 | Participant)). Autistic traits and age were

284    median-centred and scaled. Data from the two allocentric conditions (Conditions 1 and 3) were

285    collapsed together to compare body influence during interaction perception across allocentric and

286      egocentric FoR (see supplementary information 1). Sixteen influential observations (4.5%) were

287      excluded based on the criterion Cook's D greater than 4 times the average Cook's D (> 0.25).

288      Significance of fixed effects from the mixed model were determined using Satterthwaite

289      approximations of degrees of freedom using the lmerTest package, limiting Type 1 errors but

290      maintaining power (Luke, 2017).

291

292      **Results and Discussion**

293      As shown in Figure 3A, the head orientation at which the peak of interacting responses was observed

294      differed across body orientations. One sample t-tests showed that body influence was significantly

295      different from zero across both allocentric ($t\,(235) = 28.42$, $p < 0.001$) and egocentric ($t\,(117) = 22.90$,

296      $p < 0.001$) FoR. This suggests that body orientation is integrated with head orientation information

297      when perceiving social interactions across different FoR. Additionally, as illustrated in Figure 3A,

298      participants perceived the moving avatar to be looking further away from the veridical direction of the

299      head and in the direction opposite the body when the body was oriented to the left or to the right,

300      demonstrating an overshoot effect; this was confirmed by positive body influence values in both

301      allocentric (estimated marginal mean (EMM) = 3.54°, SE = 0.15, 95% CI [3.25, 3.83]) and egocentric

302      (EMM = 4.08°, SE = 0.16, 95% CI [3.76, 4.41]) FoR.

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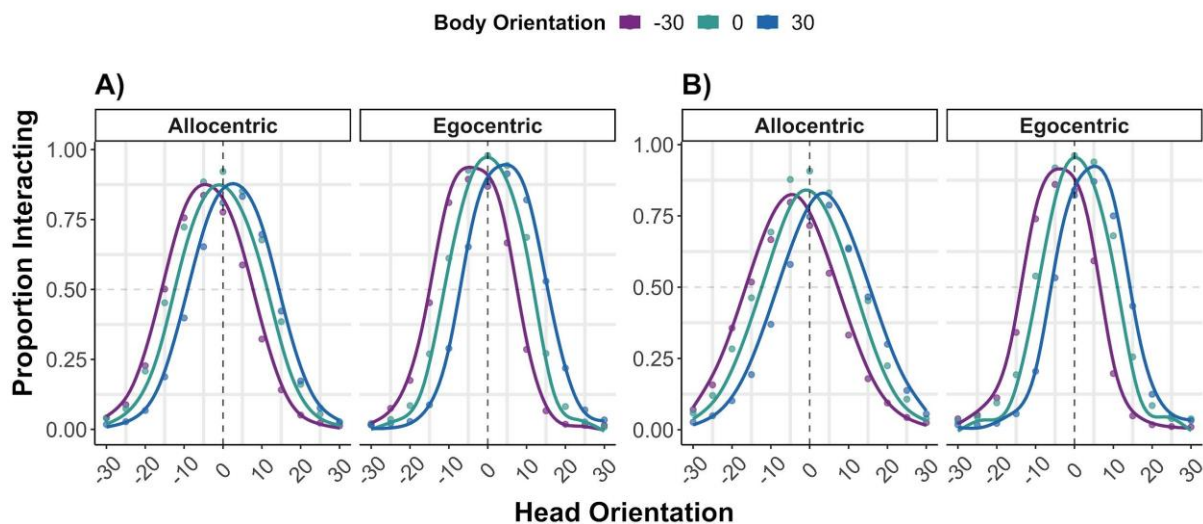


304

305    *Figure 3.* Responses to the 2AFC tasks; participants judged whether a dyad was interacting or not in

306    (A) Experiment 1 and (B) Experiment 2. The vertical dashed lines intersecting 0° on the x-axis

307    represent the head orientation at which the highest number of interacting responses should be

308    observed if body information is not integrated with head information and has no influence on

309    interaction perception. The peaks of the curves represent the head orientation at which participants

310    mostly perceive the dyads to be interacting. The filled points show the actual proportion of responses,

311    while the solid lines are calculated as the difference between two logistic functions, fitted by

312    minimising the sum of squared error of the data points from the solid lines (data are averaged over all

313    participants for illustration purposes).

314

315        The linear mixed-effects model (Table 1) revealed that the influence of the body on

316    interaction perception was significantly predicted by FoR (Figure 4A); the influence of the body,

317    which corresponded to an overshoot effect, was larger during the egocentric FoR compared to the

318    allocentric FoR ($\beta = 0.26$, SE $= 0.06$, $t$ (217.58) $= 4.03$, $p < 0.001$, 95% CI [0.13, 0.39]).

319

320    Experiment 1 sought to investigate whether observers integrate directional cues from the body and the

321    head when judging whether two people are interacting, while manipulating FoR and measuring

322    participant-reported autistic traits. In line with previous studies investigating cue integration during

323    the perception of isolated individuals (Moors et al., 2015), we found that participants integrated body

324    information with head orientation information when perceiving social interactions. Additionally, we

325    replicated the overshoot effect observed in studies investigating eye and head integration (Moors et

326    al., 2016) and head and body integration (Moors et al., 2015).

327

328        Furthermore, we found that observers integrated head and body cues differently across

329    allocentric and egocentric FoR. Participants were more influenced by the body, corresponding to a

330    stronger overshoot effect, in the egocentric compared to the allocentric FoR. It is possible that

331    participants were weighting the directional cues differently depending on whether they were making

332 egocentric (i.e. self-referential) compared to allocentric judgments. However, the increased saliency

333 of the body cue in the egocentric condition might be driving this difference. One possibility is that the

334 eye region of the interactant was less visible in the egocentric condition (Condition 2 in Figure 2)

335 compared to the allocentric conditions. This relative lack of visibility could have resulted in a greater

336 reliance on body directional cues for making the required judgement.

337

338    We found no relationship between autistic traits and cue integration during interaction

339 perception, nor an interaction between autistic traits and FoR in Experiment 1 (Figure 5A). Previous

340 research has shown that autism is associated with differences in cue integration during gaze

341 perception (Ashwin et al., 2015; Mihalache et al., 2020); autistic participants utilise information from

342 the eyes less than non-autistic participants (Mihalache et al., 2020) and focus more on body

343 information (Ashwin et al., 2015) when judging gaze direction. Indeed, diminished attention to others'

344 eyes is an early symptom of ASC (Jones & Klin, 2013). The gaze aversion hypothesis proposes that

345 autistic individuals avoid looking at others' eyes as they find direct eye-contact socially threatening

346 (Kylliäinen & Hietanen, 2006; Joseph, Ehrman, McNally, et al., 2008; Hutt & Ounsted, 1966;

347 Kliemann, Dziobek, Hatri, et al., 2010). While interpreting the lack of evidence needs to be done with

348 caution, a possible explanation for not finding an effect of autistic traits on cue integration during

349 interaction perception in our study could be because observers were only required to integrate head

350 and body information of dyads, as opposed to also having to integrate eye-region information.

351 Consequently, it may be that individuals reporting more autistic traits show no differences in

352 integrating head and body cues alone, but might show differences when eye-region information is

353 visible. In light of the above, Experiment 2 sought to investigate whether autistic traits affect cue

354 integration when observers judge whether two individuals are interacting, when their eye-regions,

355 heads, and body information are visible.

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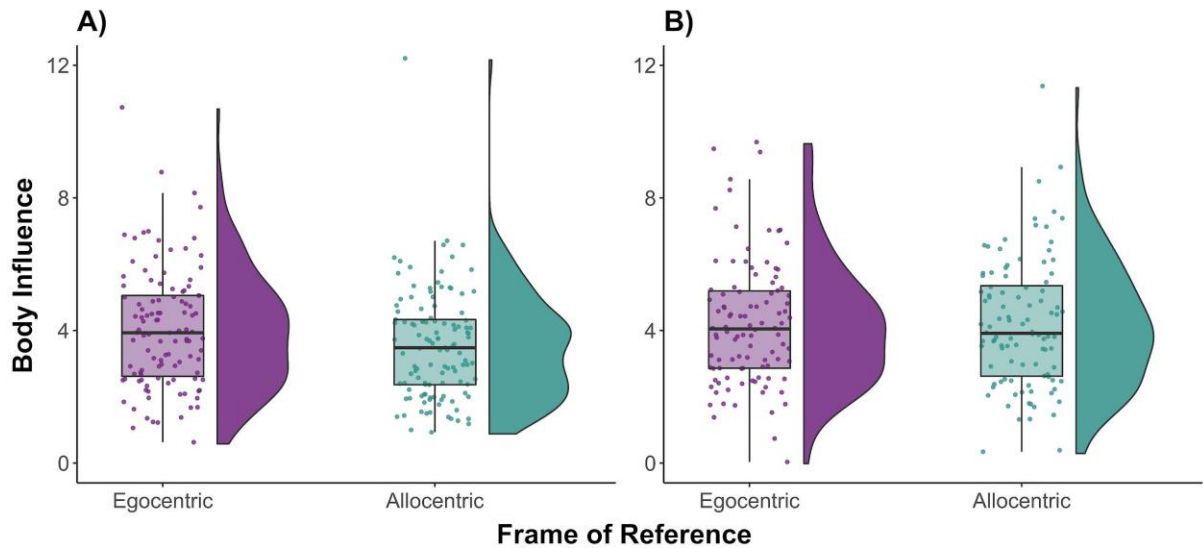
357

358  *Figure 4.* Body influence across FoR in (A) Experiment 1 and (B) Experiment 2. The coloured points

359  show each participant's body influence values, the boxplots represent the 25th and 75th percentiles,

360  and the whiskers represent upper and lower values within 1.5*interquartile range. The 'violins' show

361  the distribution of the data, and their widths correspond to the probability density at each body

362  influence value.

363

364  **Experiment 2**

365  **Methods**

366  Methods were the same in Experiment 2 as Experiment 1, except for a change in stimuli as detailed

367  below.

368
369  **Participants**
370
371  112 participants, who were distinct from the participants in Experiment 1, were recruited in the same

372  manner as in Experiment 1. After applying the exclusion criteria as previously described, N=104

373  participants remained in the analysis ($M_{age}$ = 37.15, SD = 7.06, 48 females). All participants provided

374  informed consent and the experiment was conducted in line with ethical guidelines presented in the

375  6th (2008) Declaration of Helsinki.

376

377  **Stimuli**

378    The stimuli in Experiment 2 remained the same as the stimuli presented in Experiment 1, with the

379    crucial exception that the eye-region of the avatars were visible (Figure 2B). The eye direction was

380    aligned with that of the head (i.e the orientation of the eyes always moved congruently with the

381    orientation of the head).

382

383    **Procedure**

384    Participants completed the same task as described in Experiment 1, except for the change in stimuli as

385    detailed above. After completing the experimental task, participants completed the AQ questionnaire

386    ($M = 19.91$, $SD = 7.76$).

387

388    **Data Analysis**

389    Analysis was conducted in the same manner for Experiment 2 as detailed in Experiment 1. Following

390    the same exclusion criteria after data processing but before data analysis, inspection of data from

391    excluded participants revealed that N=5 participants responded only to the orientation of the body and

392    not to the orientation of the moving avatar's head, whilst N=3 appeared to respond randomly to the

393    task.

394

395    As in Experiment 1, data from the two allocentric conditions were collapsed together to compare body

396    influence during interaction perception across allocentric and egocentric FoR (see supplementary

397    information 1). After fitting the data to the linear mixed-model, 15 influential observations (4.8%)

398    were excluded based on the Cook's D criterion greater than 4 times the average Cook's D (> 0.26).

399

400    **Results**

401    As observed in Experiment 1, one sample t-tests showed that body influence was significantly

402    different from zero across both allocentric ($t (207) = 26.52$, $p < 0.001$) and egocentric ($t (103) = 21.53$,

403    $p < 0.001$) FoR (Figure 3B). This suggests that body orientation is integrated with head orientation

404    information when perceiving social interactions across different FoR. Additionally, as shown in

405   Figure 3B, participants perceived the moving avatar to be looking further away from the veridical

406   direction of the head when the body was oriented to the left or to the right, demonstrating an

407   overshoot effect (i.e. interaction was perceived in the direction opposite the body orientation); this

408   was confirmed by positive body influence values in both allocentric (EMM = 4.24°, SE = 0.18, 95%

409   CI [3.89, 4.60]) and egocentric (EMM = 4.24°, SE = 0.20, 95% CI [3.85, 4.63]) FoR.

410

411   The results from the linear mixed-model (Table 1) showed no significant effect of FoR ($\beta$ < -0.01, SE

412   = 0.07, $t$ (188.20) = -0.02, $p$ = 0.981, 95% CI [-0.14, 0.14]; Figure 4B). However, a significant effect

413   of autistic traits was observed ($\beta$ = 0.35, SE = 0.18, $t$ (97.65) = 2.03, $p$ = 0.046, 95% CI [0.01, 0.70]),

414   and a marginally significant interaction between FoR and autistic traits ($\beta$ = -0.13, SE = 0.07, $t$

415   (187.58) = -1.91, $p$ = 0.057, 95% CI [-0.27, 0.01]; Figure 5B). Simple slopes analyses were performed

416   on the marginal interaction effect. The slope of autistic traits was significantly different from zero in

417   the egocentric FoR ($\beta$ = 0.49, SE = 0.20, t = 2.48, $p$ = 0.01), but not in the allocentric FoR ($\beta$ = 0.22,

418   SE = 0.18, t = 1.23, $p$ = 0.22).

419

420   **Exploratory Analysis and Results**

421   While a significant relationship between autistic traits and body influence was found in Experiment 2,

422   this relationship was not observed in Experiment 1. Conversely, a significant relationship between

423   FoR and body influence was found in Experiment 1, but this was not shown in Experiment 2.

424   Although two different samples of participants were tested across experiments, the only difference in

425   experimental design is the eye-region visibility of the dyads. Thus, the findings were further explored

426   by combining the two independent datasets from Experiment 1 and Experiment 2 (n.b. this

427   exploratory analysis was not pre-registered) and fitting the data to a linear mixed-effects model using

428   restricted maximum-likelihood (formula: Body Influence ~ FoR * Autistic Traits * Experiment + Age

429   + Gender + (1 | Participant ID)).

430

431    Twenty-nine influential observations (4.4%) were excluded based on the Cook's D criterion greater

432    than 4 times the average Cook's D (> 0.15). The model (Table 2) showed significant effects of FoR ($\beta$

433    = -0.13, SE = 0.05, $t$ (410.45) = -2.78, $p$ = 0.006, 95% CI [-0.23, -0.04]) and autistic traits ($\beta$ = 0.25,

434    SE = 0.12, $t$ (216.10) = 2.18, $p$ = 0.031, 95% CI [0.03, 0.48]), a significant two-way interaction

435    between FoR and experiment ($\beta$ = 0.11, SE = 0.05, $t$ (410.59) = 2.38, $p$ = 0.019, 95% CI [0.02, 0.21])

436    and a three-way interaction between FoR, experiment, and autistic traits ($\beta$ = -0.12, SE = 0.05, $t$

437    (408.18) = -2.59, $p$ = 0.010, 95% CI [-0.22, -0.03]; Figure 5).

438
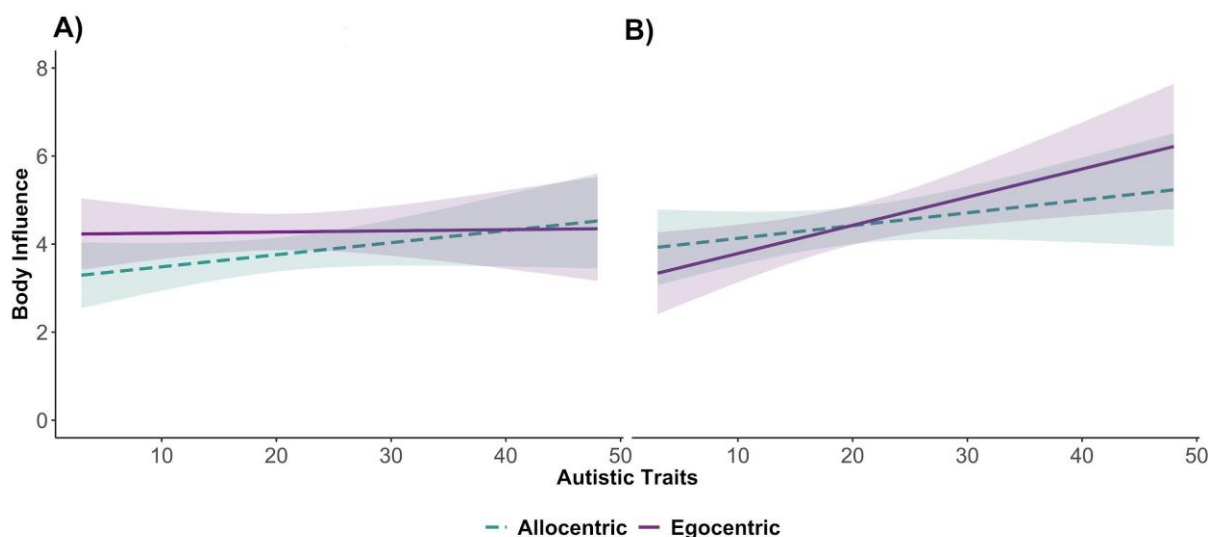


439

440    *Figure 5.* Body influence values in (A) Experiment 1 and (B) Experiment 2, across FoR and as a

441    function of autistic traits.

442

443    To investigate the significant two-way interaction between the categorical fixed effects, Tukey-

444    adjusted pairwise comparisons were performed using the R package 'emmeans' (Lenth et al., 2019).

445    This showed that the influence of the body on interaction perception was larger when the eyes were

446    visible in Experiment 2 in the allocentric FoR, compared to when the eyes were obscured in

447    Experiment 1 ($\beta$ = 0.66, SE = 0.24, $t$ (250) = 2.80, $p$ = 0.028). Additionally, the influence of the body

448    on interaction perception was larger during the egocentric condition compared to the allocentric

449    condition when the eyes were obscured in Experiment 1 ($\beta$ = -0.51, SE = 0.13, $t$ (414) = -3.99, $p$ =

450    0.001), and during the egocentric condition when the eyes were visible (Experiment 2) compared to

451    the allocentric condition when the eyes were obscured (Experiment 1)($\beta = 0.67$, SE = 0.25, $t$ (301) =

452    2.69, $p = 0.038$).

453

454    Simple slopes analyses to investigate the three-way interaction effect (Figure 5) showed that the slope

455    of autistic traits was significantly different from zero in the egocentric FoR when the eye-region was

456    visible in Experiment 2 ($\beta = 0.53$, SE = 0.20, t = 2.61, $p = 0.01$), but not when the eye-region was

457    obscured in Experiment 1 ($\beta = 0.02$, SE = 0.17, t = 0.13, $p = 0.90$).

458

459    **General Discussion**

460    Experiment 2 sought to replicate the findings from Experiment 1 and further explore whether autistic

461    traits affect cue integration during perception of social interactions when the eye-regions, heads, and

462    bodies of dyads are visible. In line with Experiment 1, we found that body orientation is indeed

463    integrated with head orientation when perceiving social interactions. Additionally, we replicated the

464    overshoot/repulsive effect of body orientation on interaction perception, such that perceived

465    interaction is shifted away from body orientation when head and body cues are misaligned. This is

466    consistent with previous findings that body orientation exerts a repulsive influence on head orientation

467    (Moors et al., 2015), and head orientation exerts a repulsive influence on gaze direction (Moors et al.,

468    2016; Otsuka et al., 2014, 2015).

469

470         As discussed in the introduction, an explanation for the overshoot effect was proposed by

471    Anstis et al. (1969) and Otsuka et al. (2014). Namely, an overshoot effect is created when the visible

472    amount of white sclera on either side of the iris changes when a person's eyes are fixated while the

473    head rotates. Information from the eye-region was not visible to observers in Experiment 1, and

474    extracting detailed information from the eye-region would be difficult in Experiment 2. Further, as the

475    eyes were always aligned with the head such that any information extracted from these cues would be

476    congruent with each other, and the visible amount of sclera did not change across head rotations, it is

477    not possible for the overshoot effect observed in our experiments to be explained by a change in eye-

478    region information. A recent study by Moors et al. (2015) observed that the overshoot effect of the

479    body increased with increasing misalignment between head and body cues; the authors suggest that

480    increased misalignment between head and body cues in a looker creates a strong directional spatial

481    code, indicating that the person is shifting their attention, thus observers might implicitly assume that

482    gaze is not aligned with the head due to implied motion. Therefore, observers in our study might have

483    assumed that the eyes of the avatar were not aligned with the head because the misaligned head and

484    body cues imply that the moving avatar is shifting its attention. It would be interesting for a future

485    study to investigate the overshoot effect using stimuli where information from the body, head, and

486    eye-region are all clearly visible to observers and are manipulated independently, in order to

487    disentangle each cue's influence on the overshoot effect.

488

489          In contrast to Experiment 1, observers did not integrate head and body cues differently across

490    allocentric and egocentric FoR in Experiment 2. Participants in Experiment 1 showed a stronger

491    overshoot effect of the body during the egocentric compared to the allocentric FoR, whereas

492    participants in Experiment 2 were influenced by the body to the same extent across FoR; this was

493    confirmed by a significant interaction between experiment and FoR in the exploratory analysis (Table

494    2). Given that the eye-region, a salient directional cue, is not visible in Experiment 1, it is possible

495    that the relative weightings of head, body, and eye-region information differ to their weightings in

496    Experiment 2. Where there is increased uncertainty for the eye-region cue in Experiment 1, the

497    relative weights attached to the eye-region and potentially the head orientation will be reduced,

498    consequently increasing the weighting of the body cue and increasing the overshoot effect,

499    particularly in the egocentric condition where the body cue is most salient. This is consistent with

500    previous discussions by Perrett and colleagues (1992) and Otsuka and colleagues (2014), who assume

501    that weights attached to each directional cue during gaze perception are not fixed, but vary according

502    to the viewing conditions (Gamer & Hecht, 2007), context (Balsdon & Clifford, 2018), and the

503    information available within the stimuli.

504

505        Unlike Experiment 1, a relationship between autistic traits and the influence of the body on

506    interaction perception was observed in Experiment 2; participants with higher AQ scores had higher

507    body influence values (i.e. exhibiting a stronger overshoot effect) than those with lower AQ scores.

508    The marginal interaction between autistic traits and FoR in Experiment 2 (Table 1) demonstrated that

509    observers with high AQ scores were influenced more by the body in the egocentric than in the

510    allocentric condition; this effect was supported by a significant three-way interaction between autistic

511    traits, FoR, and experiment in the exploratory analysis (Table 2). Notably, the only difference

512    between Experiments 1 and 2 was the visibility of the eye-regions of the dyads; thus, it is possible that

513    the discrepancies in findings across experiments is due to whether or not the eye-region is visible to

514    observers. As previously discussed, autistic individuals utilise eye information less than non-autistic

515    participants when making judgments about gaze (Mihalache et al., 2020), and focus more on body

516    information than head and eye information in a spatial cueing paradigm (Ashwin et al., 2015).

517    Additionally, the gaze aversion hypothesis (Kylliäinen & Hietanen, 2006; Joseph, Ehrman, McNally,

518    et al., 2008; Hutt & Ounsted, 1966; Kliemann, Dziobek, Hatri, et al., 2009) suggests that autistic

519    individuals actively avoid looking towards the eye-region because they find the eyes aversive.

520    Accordingly, individuals reporting more autistic traits in Experiment 2 might assign lower weightings

521    to eye-region and head orientation cues of dyads when perceiving interactions, thus becoming more

522    susceptible to the repulsive effect of the body.

523

524        However, the effect of AQ was only observed in the egocentric FoR; it is possible that

525    participants with more autistic traits find a frontal-view of the eyes more aversive than a side-view of

526    the eyes, leading to reduced attention to the eye and head cues in this condition. Relatedly, it could be

527    argued that the effect of AQ is observed only when participants engage in self-referential judgements.

528    Indeed, patients with schizophrenia (Hooker & Park, 2005; Rosse, Kendrick, Wyatt, et al., 1994; Tso,

529    Mui, Taylor, & Deldin, 2012) and social-anxiety (Harbort et al., 2013; Gamer et al., 2011; Schulze,

530    Lobmaier, Arnold, & Renneberg, 2013; Jun et al., 2013; Schulze, Renneberg, & Lobmaier, 2013)

531    show differences in self-referential gaze perception. Additionally, Balsdon and Clifford (2018)

532 observed that participants weighted head and eye cues differently depending on whether they were

533 making directional (i.e. allocentric) or self-referential (i.e. egocentric) judgements. It is important to

534 note that the stimuli presented in our study acted only as proxies for egocentric and allocentric FoR;

535 we acknowledge that the ecological validity of these stimuli is limited due to the unnatural positioning

536 of the camera in both conditions. It would be interesting for future studies to compare the influence of

537 the body on interaction perception in tasks more directly comparing directional vs. self-referential

538 judgments.

539

540        In interpreting our findings, it is important to consider the limitations. Firstly, both

541 experiments discussed in this paper were conducted completely online during the covid-19 pandemic.

542 Although there has recently been a surge in research conducted online, and carefully designed online

543 experiments can offer reliable data that is indistinguishable from data collected in the lab (Germine et

544 al., 2012; Crump et al., 2013), we acknowledge limitations associated with online testing, especially

545 the lack of control of a participant's environment including their viewing distance and angle (though

546 see Heer et al., 2010 and Liu et al., 2018). Nevertheless, it is promising that we demonstrated that

547 participants integrate body information with head information when perceiving social interactions,

548 and replicated the previously found overshoot effect, across two large-sampled experiments.

549 Secondly, although we report a relationship between autistic traits and interaction perception, we do

550 not know whether this relationship extends to participants with clinical ASC diagnoses. It would be

551 valuable for future studies to attempt to replicate our findings in a lab-setting among a sample with a

552 clinical diagnosis of ASC. Thirdly, in favour of experimental control, static displays of social

553 interactions were presented to participants; although this allowed for easier presentation of various

554 combinations of head and body angles, we acknowledge that real-world perception of social

555 interaction is much more dynamic and unpredictable, and our results provide only a first

556 approximation of cue integration during perception of social interactions in the real world. Indeed,

557 dynamic stimuli might convey more information about the intentions of the dyads, and might thus

558 lead to different integration of eye, head, and body information. Relatedly, although the eye-region of

the dyads was not occluded in Experiment 2, observers would be limited in their ability to extract detailed information about the direction in which their eyes were pointing. Thus, any effects of eye-region visibility observed in our study might be due to observers implicitly assuming where the eyes of the dyads were looking.

The results of this study indicate that body information is integrated with head information when perceiving social interactions, such that perceived interaction is shifted away from body orientation when head and body cues are misaligned. Additionally, our findings suggest that autistic traits and FoR affect cue integration during interaction perception, but that these effects are dependent on the visibility of the eye-region. The results provide crucial first insights into how directional cues are integrated during interaction perception across different contexts, as well as an important contribution to our understanding of social cue integration in individuals with and without autism.

**Table 1. Linear mixed-effects model summary for Experiment 1 and Experiment 2**

| | Experiment 1 | | | | Experiment 2 | | | |
|---|---|---|---|---|---|---|---|---|
| *Predictors* | β | *CI* | *T* | *p* | β | *CI* | *T* | *p* |
| Frame of Reference (FoR) | 0.26 | 0.13 – 0.39 | 4.03 | **<0.001** | -0.00 | -0.14 – 0.14 | -0.02 | 0.981 |
| Autistic Traits (AQ) | 0.11 | -0.17 – 0.39 | 0.77 | 0.440 | 0.35 | 0.01 – 0.70 | 2.03 | **0.044** |
| Age | -0.00 | -0.29 – 0.28 | -0.03 | 0.976 | 0.23 | -0.12 – 0.58 | 1.31 | 0.192 |
| Gender | 0.27 | -0.01 – 0.54 | 1.90 | 0.058 | 0.09 | -0.26 – 0.43 | 0.51 | 0.613 |
| FoR * AQ | -0.09 | -0.22 – 0.03 | -1.46 | 0.144 | -0.13 | -0.27 – 0.00 | -1.91 | 0.057 |

**Random Effects**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\sigma^2$ | 1.21 | | | | 1.27 | | | |
| $\tau_{00}$ | 1.87 $_{PID}$ | | | | 2.64 $_{PID}$ | | | |
| ICC | 0.61 | | | | 0.68 | | | |
| N | 118 $_{PID}$ | | | | 104 $_{PID}$ | | | |
| Observations | 338 | | | | 297 | | | |
| Marginal $R^2$ | 0.052 | | | | 0.044 | | | |

**Table 1. Linear mixed-effects model summary for Experiment 1 and Experiment 2**

| Predictors | Experiment 1 | | | | Experiment 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | β | *CI* | *T* | *p* | β | *CI* | *T* | *p* |
| Frame of Reference (FoR) | 0.26 | 0.13 – 0.39 | 4.03 | **<0.001** | -0.00 | -0.14 – 0.14 | -0.02 | 0.981 |
| Conditional R² | 0.628 | | | | 0.690 | | | |

**Table 2. Linear mixed-effects model summary for Exploratory Analysis**

| Predictors | β | CI | T | p |
|---|---|---|---|---|
| | | **Exploratory Analysis** | | |
| Frame of Reference (FoR) | -0.13 | -0.23 – -0.04 | -2.78 | **0.006** |
| Autistic Traits (AQ) | 0.25 | 0.03 – 0.48 | 2.18 | **0.030** |
| Experiment (Exp) | 0.22 | -0.01 – 0.45 | 1.89 | 0.059 |
| Age | 0.09 | -0.14 – 0.32 | 0.76 | 0.450 |
| Gender | 0.17 | -0.06 – 0.39 | 1.46 | 0.144 |
| FoR * AQ | -0.02 | -0.12 – 0.07 | -0.44 | 0.658 |
| FoR * Exp | 0.11 | 0.02 – 0.21 | 2.36 | **0.019** |
| AQ * Exp | 0.13 | -0.10 – 0.36 | 1.11 | 0.266 |
| FoR * AQ * Exp | -0.12 | -0.22 – -0.03 | -2.59 | **0.010** |

**Random Effects**

| | |
|---|---|
| $\sigma^2$ | 1.24 |
| $\tau_{00\ PID}$ | 2.41 |
| ICC | 0.66 |
| $N_{PID}$ | 222 |
| Observations | 637 |
| Marginal $R^2$ | 0.051 |
| Conditional $R^2$ | 0.679 |

**Supplementary Information 1**

In order to investigate whether allocentric and egocentric frames of reference influence cue integration during interaction differently, data from the two allocentric conditions (Conditions 1 and 3) were collapsed together. Paired samples t-tests confirmed that Condition 1 and Condition 3 were not statistically different from each other in neither Experiment 1 nor 2 (Table S1).

**Table S1. Results of paired t-tests comparing means from Conditions 1, 2, and 3.**

|  | Mean difference | t | df | 95% CI | *p* |
|---|---|---|---|---|---|
| *Experiment 1* |  |  |  |  |  |
| Condition 1 v Condition 2 | -0.67 | -4.08 | 117 | -1.00 - -0.35 | **<0.001** |
| Condition 1 v Condition 3 | -0.20 | -1.39 | 117 | -0.49 - 0.08 | 0.17 |
| Condition 2 v Condition 3 | 0.47 | 2.57 | 117 | 0.11 - 0.84 | **0.01** |
| *Experiment 2* |  |  |  |  |  |
| Condition 1 v Condition 2 | -0.02 | -0.07 | 103 | -0.45 - 0.41 | 0.94 |
| Condition 1 v Condition 3 | -0.13 | -0.69 | 103 | -0.50 - 0.24 | 0.49 |
| Condition 2 v Condition 3 | -0.11 | -0.65 | 103 | -0.46 - 0.23 | 0.52 |

*Condition 1 = allocentric, Condition 2 = egocentric, Condition 3 = allocentric.*
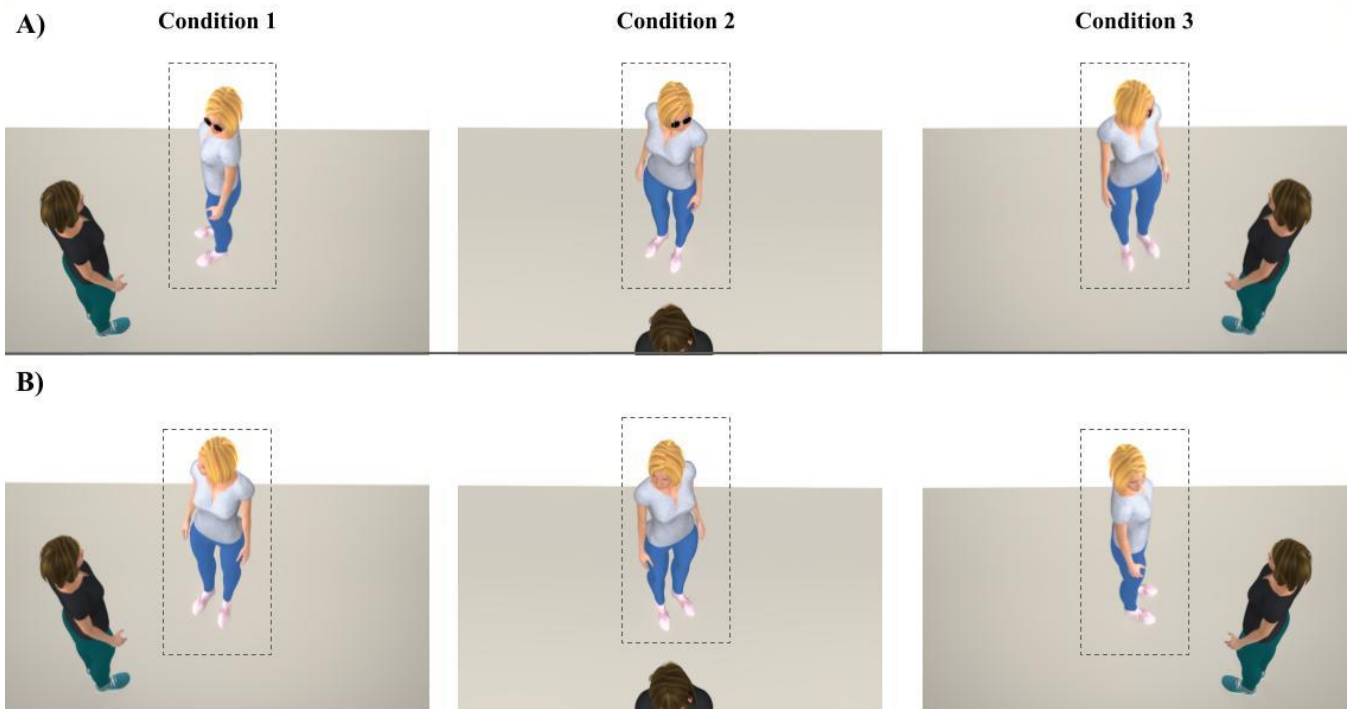
*Supplementary Figure 1.* Additional examples of stimuli presented in (A) Experiment 1 and (B) Experiment 2. The head orientation of the moving avatar (outlined with a dashed rectangle for illustration purposes) is set at +20° in the examples shown above in (A) and -20° in (B). The body orientation of the moving avatar is set at -30° in the examples shown above in (A) and +30° in (B).

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