Human body motion captures visual attention and elicits pupillary arousal

Elin H. Williams¹, Fil Cristino² & Emily S. Cross^{3*}

¹ School of Psychology, Bangor University, Bangor, Wales

² School of Psychology, Nottingham Trent University, Nottingham, England

³ Institute of Neuroscience and Psychology, School of Psychology, University of Glasgow, Glasgow, Scotland

* to whom correspondence should be addressed:

Emily S. Cross
Institute of Neuroscience and Psychology
School of Psychology
University of Glasgow
62 Hillhead Street
Glasgow
G12 8QB
emily.cross@glasgow.ac.uk

Abstract: 150 words

Main Text Word Count (whole manuscript): 5493

Words (not including methods/results): 2000

References: 39

Abstract

The social motivation theory proposes that individuals naturally orient their attention to the social world. Here, we used complementary eye tracking measures to investigate how social motion cues affect attention and arousal. Specifically, we examined whether viewing the human body moving naturally versus mechanically leads to greater attentional engagement and changes in autonomic arousal (as assessed by pupil size measures). This question is based on previous research documenting the rewarding value of biological motion to typically developed individuals. Participants completed an attentional disengagement task in two independent experiments, while pupillary responses were recorded. We found that natural, human-like motion produced greater increases in attention and arousal than mechanical motion, whether the moving agent was human or not. These findings contribute an important piece to our understanding of social motivation by demonstrating that human motion is a key social stimulus that engages visual attention and induces autonomic arousal in the viewer.

Keywords: Biological motion, social reward, social motivation, pupillometry, eye-tracking, attentional disengagement, autonomic arousal, autistic traits

Introduction

From birth, humans show social motivation – a strong preference for social stimuli (Dawson et al., 1998; Chevallier et al., 2012; Fletcher-Watson et al., 2008), as demonstrated by our reliable attentional preferences for biologically relevant stimuli including faces, voices, and the human body (Valenza, Simion, Cassia, & Umiltà, 1996; Alegria & Noirot, 1978; Fox & McDaniel, 1982). Such social stimuli, such as dynamic and static displays of human faces and bodies, provide valuable information about an observed individual, including their age, gender, race, identity, emotions and intentions. Reduced social motivation is suggested to cause deficits in social reward processing, which might have negative downstream consequences for social cognition in conditions such as Autism Spectrum Disorders (ASD; Chevallier et al., 2012).

In 2005, Senju and Hasegawa provided evidence for social motivation (Senju & Hasegawa, 2005). They used an attentional disengagement task to demonstrate that typically developed (TD) participants detect peripheral targets more slowly when viewing facial images displaying direct versus averted gaze. These slower reactions to targets could be due to increased attentional dwell time given to facial stimuli that convey biologically important information (Fox & McDaniel, 1982). Individuals with ASD, however, show no differences in attentional dwell time when shown faces or non-social objects (Kikuchi et al., 2013). Other studies have reported preferential attention given to biological motion (motion patterns associated with living organisms), which is crucial for facilitating adaptive interactions across phylogeny (Bardi, Regolin, & Simion, 2011). Evidence also shows that TD infants naturally attend to biological motion (Fox & McDaniel, 1982), and that this behaviour is impaired in infants with autism (Klin et al., 2009).

Many prior studies have shown that social information captures attention easily because most people find social signals rewarding. Recent studies have therefore used effort tasks to better understand and measure the reward value of social stimuli (Dubey, Ropar, & Hamilton, 2015; Williams & Cross, 2018). These studies report that TD individuals exert more effort to view videos of faces with a direct gaze, compared to non-social objects (Dubey et al., 2015), and to view videos of humans moving naturally compared to mechanistically, further reinforcing the reward value of socially relevant stimuli (Williams et al., 2018). Participants reporting more autistic traits or with ASD diagnoses showed a reduced preference for social stimuli across both studies.

While explicit preference tasks provide a useful means to investigate social reward, another promising approach involves measuring pupil dilation to assess implicit and automatic reward processing. Sepeta and colleagues (2012) used pupillary reactions to measure autonomic responses (as a proxy for arousal) of children with and without ASD when viewing facial images. They found TD children showed greater pupil dilation when viewing images of happy faces showing direct versus averted gaze. This association with gaze direction was absent among children with ASD. Thus, increased pupil diameter among TD children when directly viewing happy faces might reflect the intrinsic reward value of a face looking directly at the observer. Indeed, the rewarding value of faces to TD participants is well established (Dubey et al., 2015). The absence of increased pupil diameter among children with ASD suggests they have reduced sensitivity to the reward value of this stimulus. However, we do not know whether other salient social cues, such as biological human body motion, also engage attention more than non-social cues do. We also do not

know the extent to which socially relevant body form and body motion cues might induce autonomic responses due to their rewarding value.

Here, we test the hypothesis that attention is engaged more by naturalistic than by mechanistic motion, and by a human body compared to a non-human figure, using two different eye-tracking experiments performed with TD individuals. We measured the time participants took to disengage attention from different stimuli and attend to peripheral targets, using saccades as a measure of attentional disengagement in Experiment 1, and a button-press response measure in Experiment 2. We hypothesised that, due to the social importance of biological motion, participants should show the longest attentional dwell time for natural motion performed by a human body (shown by delayed saccadic response times in Experiment 1, and by delayed behavioural response times in Experiment 2). Although our main objective was to investigate participants' engagement with natural compared to machine-like motion, our experimental design enabled us to investigate whether it is the social nature of form or motion cues (or both) that individuals find most engaging. We also predicted that individuals reporting more autistic traits would show less pronounced differences in attentional dwell time for videos of natural compared to mechanistic motion, whereas those reporting fewer autistic traits would be slower to disengage from natural than mechanistic motion. We also evaluated whether differences in pupil size emerge while participants view the different videos to test the hypothesis that participants would show greater pupil dilation when viewing videos of human bodies moving naturally compared to other videos. We also examined the relationship between autistic traits and pupil size when viewing different videos.

Experiment 1

Previous studies of attentional disengagement have primarily measured attentional dwell time via button responses to peripheral targets. However, measuring attentional disengagement by saccades is thought to highlight more subtle differences in response times (Belopolsky, Devue, & Theeuwes, 2011; Azarian, Esser, & Peterson, 2016). In light of this, participants in Experiment 1 completed an attentional disengagement task where they watched a video until a peripheral target appeared, at which time they were asked to saccade toward the peripheral target.

Materials and Method

Participants

Fifty-one participants were recruited from the local community or from Bangor University's student participant panel. Data from one participant were excluded due to a technical issue that resulted in data from a quarter of the trials not being recorded, and one further participant was excluded due to having an Autism Quotient score more than 2 standard deviations away from the mean, leaving a final sample for data analysis of 49 participants (35 females; $M_{\text{age}} = 23.80$, $SD_{\text{age}} = 4.79$). Participants were reimbursed £7 per hour or were given course credits for their time. The sample size was determined prior to data collection using the G*Power calculator (Faul, Erdfelder, Lang, & Buchner, 2007; Faul, Erdfelder, Buchner, & Lang, 2009), which enabled us to detect medium-to-large effect sizes with 80% power. However, this sample was determined for analyses using repeated-measures ANOVA rather than mixed-effects modelling, due to the complexity of conducting power analyses for experiments employing mixed-effects models (Kain, Bolker & McCoy, 2015). All

participants had normal or corrected-to-normal vision, provided written informed consent, and Bangor University's School of Psychology Research Ethics Committee granted ethical approval (Ethics Approval Code: 2015-15400), following procedures in accordance with the Declaration of Helsinki.

Stimuli

Four categories of video stimuli developed for a previous study (Williams & Cross, 2018) were used. The first and second category of videos featured a human actor performing Natural Human Motion (movements such as moving arms and legs from side to side smoothly) and Machine-Like Motion (movements such as moving arms and legs from side to side rigidly). These two stimulus categories included 10 unique videos each, and are henceforth referred to as 'Human Body Natural Motion' and 'Human Body Machine-Like Motion', respectively. Human Body Natural Motion videos were created as a proxy for biological motion, and Human Body Machine-Like Motion videos were created as a proxy for non-biological motion (for further discussion of the utility of this approach, please see Williams and Cross, 2018).

Videos were captured using the Kinect platform (Microsoft), where a video stream and the agent motion structure were extracted. From these video recordings, ten CGI videos featuring a non-human control figure "performing" both Natural Motion and Machine-Like Motion were created using the same motion as the human ones; these are referred to as Control Figure Natural Motion and Control Figure Machine-Like Motion (Figure 1). Participants saw each stimulus for at least 2.5 seconds (i.e., the combination of the shortest stimulus onset asynchronies (SOA), plus saccade latency). The moving agents appeared without heads, as facial information might provide additional social cues that could influence task performance that we were not

explicitly interested in for this study. For more details about how the stimulus sets were created, see Williams and Cross (2018).

A static target was placed onto the torso of both the human and control figures, and the torso region remained stationary so that participants had a stable point in the video to fixate. This manipulation also allowed for more controlled pupil measurements as pupil size can change with gaze position and eye movements (Brisson, Mainville, Mailloux, Beaulieu, Serres, & Sirois, 2013).

Fluctuations in pupil size also occur as a result of changes in luminance in stimuli (Woodhouse, 1975). This pupillary light reflex has been suggested to be one of the main confounds in cognitive pupillometry (Sirois & Brisson, 2014; Woodhouse, 1975). Thus, we verified that the luminance levels of both motion categories did not significantly differ from each other. Although the luminance of the figure types (human vs. control) differed, importantly, there were no differences in luminance between the motion categories (see Supplementary Materials for full luminance analysis). Thus, we can rule out that changes we emerge between motion categories are due to low-level differences in luminance between the stimuli. The videos fell into a 2x2 factorial design, with Agent Type (human body or control figure) and Motion (natural or machine-like) as factors.

Figure 1. Example video stills from the four stimulus categories.

Apparatus

Saccadic eye-movements and pupil size were recorded from only the right eye of participants, using an EyeLink 1000 desk-mounted eye-tracker (SR Research Ltd., Mississauga, ON, Canada), which sampled at 1000 Hz. Pupil diameter was measured in arbitrary units as recorded by the eye-tracker. Participants sat in a comfortable chair, with a pillow to limit head movements, in a dimly lit room with no windows. Videos were presented in the center of a screen at a viewing distance of 100 cm. Target dots were displayed either to the left or to the right of the main video. All stimuli were presented on a 27-inch monitor with a resolution of 1080 x 1920 (60 Hz refresh rate). The stimuli subtended at the maximum 14° by 14 ° of visual angle and were presented on a white background. The experiment was presented using Experiment Builder (version 1.10.1630; SR Research Ltd, 2004).

Procedure

The experiment began with a 9-point calibration of the eye-tracker followed by a validation stage. Recalibrations took place after each experimental block, and when needed (e.g., if a participant's head moved too much, or someone wanted a break mid-block). Participants completed 1 practice block of 12 trials, followed by 4 experimental blocks of 60 trials. Participants were given the opportunity to take a break after each block.

Each trial began with a central fixation cross to perform a drift correction, followed by a video stimulus. Participants were required to maintain fixation on the circular target on the torso of the figure in the video. A target dot appeared in a non-predictive fashion to the left or to the right of the stimulus, either 2500 ms or 3000 ms after video onset (Figure 2). These 2 SOAs were chosen to give the participant enough time to perceive the different types of movements in the videos. Pupillary reactions are also slow; it was therefore necessary that the video play long enough to accurately measure pupil data. The target and the video remained on the screen until a saccade was made, or until 2000 ms had passed. Participants were instructed to move their eyes away from the target on the torso and towards the peripheral target as quickly as possible as soon as it appeared. If a saccade was made prematurely (before the onset of the target), or if the participant blinked before the onset of the target, the message 'You moved your eyes too soon!' appeared on the screen, and the trial was recycled to appear later in the block. If participants failed to make a saccade within 2000 ms of target onset, the trial was recycled and appeared later in the block.

The latency (saccadic reaction time) was defined as being the time between target onset and the saccade start time. At the end of a trial, a blank screen appeared for 2000 ms to allow the pupil size to return to baseline, and to give participants a short break. At the end of the experiment, participants completed a demographic questionnaire, which assessed their age and gender, the Autism Quotient questionnaire (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) ($M = 15.84$, $SD = 6.85$) to measure autistic traits, and the Oldfield handedness inventory (Oldfield, 1971) ($M = 69.94$, $SD = 48.19$).

Latency Data Analysis

Due to the experimental procedure set up (i.e. trials being recycled when participants moved their eyes too soon, blinked, or did not respond within 2000 ms), trials were not discarded due to participant errors. However, saccadic latencies less than 80 ms were discarded from the analyses (following procedures reported by Azarian et al., 2016), as they were unlikely to be triggered by the target onset; this led to a total of 3.76% of the saccade trials being removed.

Figure 2. Example of a trial with a video of a human body performing natural motion. Participants were asked to make a saccade from the centrally presented stimulus toward the target dot as quickly as possible in Experiment 1, and were asked to press a button in Experiment 2. Pupil size was measured from the onset of the video until the onset of the target dot.

Our primary aim was to investigate the effects of Motion, Figure, Autistic Traits, and their interactions, on participants' attention. Thus, the remaining data were analysed using linear mixed-effects models with the lme4 package (version 1.1-13; Bates, Maechler, Bolker, & Walker, 2015) in R (Version 3.3.3, R Core Team, 2016). We fitted our data to maximal models, including both random intercepts and slopes insofar as possible with respect to model convergence (Barr, Levy, Scheepers, & Tily, 2013). The final, best-fitting model predicted the time taken for participants to disengage their attention from the video and attend to the target in the periphery by modelling the interaction between Autistic Traits, Figure (a factor with 2 levels: Human or Control Figure) and Motion (a factor with 2 levels: Natural Motion or

Machine-Like Motion), and including SOA (a factor with 2 levels: 2500 ms or 3000 ms) and Target Position (a factor with 2 levels: Left or Right) as covariates. All predictors were mean-centred, and the log of saccadic response time (RT) was used as the outcome variable (to correct the positive skew in the RT distribution, Baayen & Millin, 2010). A random by-participant intercept, and random slopes for Figure, Motion, and Target Position (Barr et al., 2013) were included. The R formula for our model was:

$$\text{Log(Latency)} \sim \text{Autistic Traits} * \text{Motion} * \text{Figure} + \text{SOA} + \text{Target Position} + \\ (1 + \text{Motion} * \text{Figure} * \text{Target Position} \mid \text{Participant})$$

After running this model, the ‘romr.fnc’ function within the R package ‘LMERConvenienceFunctions’ (Tremblay & Ransijn, 2015) was used to exclude outliers from the model with standardized residuals greater than 2.5 standard deviations from 0. This removed an additional 3.06% of data from the analyses. Both models were compared using the ‘relLik’ function in R, which calculates the relative log-likelihood between two models, revealing that the model excluding outliers was a better fit. This method of removing outliers post-model fitting leads to fewer data points being removed, and to better-fitting models, compared to the more ‘aggressive’ removal of outliers prior to model fitting (Baayen & Millin, 2010). Plotting and inspecting the residuals for this model detected no violations of linearity, homoscedasticity, or normality.

Both *t* and *p*-values are reported in Table 1 due to concerns relating to *p*-values estimated from linear mixed-effects models (Bates, 2006). We used *t* > 2 as a

threshold for significance in all analyses in this study, which is comparable to $p < 0.05$ (Baayen, Davidson, & Bates, 2008). The p -values reported are Satterthwaite approximated using lmerTest (Kuznetsova, Brockhoff, & Christensen, 2015).

Pupillometry Data Analysis

Pupil data were cleaned prior to data analysis. Missing pupil data (e.g. data missing from blinks, etc.) were linearly interpolated, and data were baseline corrected. To perform baseline correction, the median pupil size during the first 10 ms of each trial for each participant was subtracted from the remaining data in that trial (Mathôt, Fabius, Heusden, & Stigchel, 2017).

The epoch of interest was from the onset of the video to 2500 ms (i.e., before the onset of the peripheral target). This led to 2500 data points per trial per participant. For each stimulus category, we aggregated the pupil data across time over all trials for each participant. This led to a data set consisting of 2500 data points per condition per participant.

Data obtained from 0 – 220 ms were not used for analysis as the effects of the experimental manipulation on pupil size should develop at the earliest from 220 ms, due to the latency of the pupillary response (Ellis, 1981; Mathôt, van der Linden, Grainger, & Vitu, 2015). The remaining data (220 – 2500 ms) were analysed with mixed-effects models via the lme4 package in R. Following Mathôt, Grainger, and Strijkers (2017), for each 10 ms time window, we conducted a linear mixed-effects model. In this model we predicted pupil size by modeling the interaction between the fixed effects: Autistic Traits, Motion, and Figure. All predictors were mean-centered.

A random by-participant intercept was included, as were random slopes for the interaction between Motion and Figure. To determine the significance of the fixed effects, we set a threshold of at least 200 contiguous milliseconds where $t > 2$. The R formula for our models was:

$$\text{Pupil Size} \sim \text{Autistic Traits} * \text{Motion} * \text{Figure} + \\ (1 + \text{Motion} * \text{Figure} \mid \text{Participant})$$

Results

Latency Results

Results from the linear mixed-effects model (Figure 3A and Table 1.1) demonstrated that the time taken for participants to disengage from a stimulus and attend to a target was significantly influenced by the category of the stimulus presented to them. This was revealed by a significant main effect of Motion, showing that participants were slower to disengage their attention from videos of natural motion compared to machine-like motion. Furthermore, participants disengaged from the video stimulus more quickly at the 3000 ms SOA compared to the 2500 ms SOA. No other significant effects or interactions were found.

Figure 3. (A) Experiment 1. The mean time taken (latency, in milliseconds) for participants to disengage their attention from each stimulus category to observe a target dot presented in the periphery, as measured by saccadic response times. (B) Experiment 2. The mean time taken (response time, in milliseconds) for participants to press a button in response to a target dot presented in the periphery. Response times are collapsed across SOA, Target Position, and Autistic Traits. The points represent individual participants, the coloured boxes represent the 25th and 75th percentiles of responses, and the whiskers represent the upper and lower values within 1.5*inter-quartile range.

Pupil Results

The results are illustrated in Figure 4A and B. In Figure 4A, pupil size is plotted across time, and Figure 4B illustrates the mean pupil size from 750 – 1000 ms, for each of the four stimulus categories. Using the significance threshold outlined above, a significant emerged between 220 – 480 ms, where participants showed a reliable increase in pupil size for videos of human bodies compared to control figures. Furthermore, from 750 – 2200 ms, a significant effect of Motion emerged, indicating that participants showed greater pupil dilation for videos of natural human motion compared to machine-like motion. Additionally, an interaction between Motion and Figure was present from 990 – 1570 ms, demonstrating that the difference in pupil

size was larger between the two control figures than between the two human bodies. No other main effects or interactions were significant. Overall, videos of natural human motion led to greater pupil dilation among our participants, suggesting they find this kind of motion more arousing than machine-like motion.

Summary

Participants were more engaged with human body motion than with (less socially relevant) machine-like motion or motion performed by control figures. For example, participants disengaged their gaze more slowly from natural versus mechanical motion. Their pupils also dilated earlier (220 – 480 ms) when viewing human versus control figures, and later (750 – 2220 ms) when viewing natural versus mechanical motion. We also found a significant interaction between Motion and Figure, whereby pupil size differences were greater between control figures than between human bodies. However, among individuals reporting more autistic traits, neither reduced attentional engagement nor reduced pupil dilation emerged when viewing familiar, natural motion. Next, we examined the relationship between eye gaze, pupil dilation and the reward value of biological motion by performing a conceptual replication with a new attention task.

Table 1. Results from the mixed-effects models investigating factors contributing to attentional disengagement in Experiments 1 and 2.

1. Experiment 1	<i>B</i>	<i>SE</i>	<i>t</i>	<i>p-value</i>
Fixed Parts				
Autistic Traits	0.006	0.016	0.392	0.696
Figure	0.001	0.016	0.276	0.783
Motion	0.008	0.002	3.763	< 0.001
SOA	-0.028	0.002	-15.40	< 0.001
Target Position	-0.003	0.006	-0.574	0.569
Autistic Traits * Figure	0.003	0.002	1.393	0.167
Autistic Traits * Motion	0.003	0.002	1.201	0.235
Figure * Motion	0.004	0.002	1.847	0.069
Autistic Traits * Figure * Motion	0.000	0.002	0.032	0.974
Random Parts				
$N_{\text{Participants}}$	49			
2. Experiment 2	<i>B</i>	<i>SE</i>	<i>t</i>	<i>p-value</i>
Fixed Parts				
Autistic Traits	0.037	0.019	1.911	0.062
Figure	-0.002	0.002	-1.074	0.288
Motion	0.010	0.002	5.238	< 0.001
SOA	-0.030	0.002	-16.080	< 0.001
Target Position	0.000	0.002	-0.041	0.968
Autistic Traits * Figure	0.000	0.002	-0.017	0.986
Autistic Traits * Motion	0.002	0.002	0.962	0.340
Figure * Motion	0.003	0.002	1.872	0.063
Autistic Traits * Figure * Motion	-0.002	0.002	-0.999	0.319
Random Parts				
$N_{\text{Participants}}$	50			

Bold font indicates *p*-values less than 0.05

Experiment 2

To replicate the attentional engagement findings of Experiment (E)1, we used new participants and a more traditional behavioural measure (button press) of attentional disengagement (Azarian et al., 2016). We hypothesised participants would show a similar pattern of attentional disengagement behaviourally as that found in E1 with saccades, and would show increased pupil dilation when viewing videos of natural versus machine-like motion, replicating the pupillometry findings of E1.

Materials and Method

Preregistration

Experiment 2 was preregistered on 4th September 2017, before any data were collected (<https://aspredicted.org/kb9p8.pdf>).

Participants

Fifty participants (25 females; $M_{\text{age}} = 20.34$, $SD_{\text{age}} = 2.57$) were recruited from the local community or from Bangor University's student participant panel, and were paid £7 per hour or were given course credits for their time. As in Experiment 1, we estimated the required sample size for our mixed-effects models from power calculations for repeated-measures ANOVA. This sample size of 50 participants enabled us to detect medium-to-large effect sizes with 80% power. All participants had normal or corrected-to-normal vision, provided written informed consent, and Bangor University's School of Psychology Research Ethics Committee granted

ethical approval (2015-15400-A13785) following procedures in accordance with the Declaration of Helsinki.

Stimuli

The same four categories of stimuli were used in Experiment 2, as described in Experiment 1.

Apparatus

The same equipment was used as for Experiment 1. The experiment was conducted in a small, dimly lit room with no windows, and videos were presented in the center of a screen, 100cm away from a chin rest.

Procedure

The task procedure was similar to that reported for Experiment 1, with the exception that participants were instructed to press the space bar as soon as a target appeared in their periphery, rather than making a saccade to the target in the periphery. If a button press was made prematurely (before the onset of the target), if the participant blinked, or if they moved their eyes before the onset of the target, the message ‘You moved your eyes or responded too soon!’ appeared on the screen, and the trial was recycled to appear later in the block. Failure to make a response within 2000 ms of the target onset resulted in the trial being recycled later in the block. The response time was calculated by subtracting the time of target onset from the button press time.

At the end of the experiment, participants completed the same questionnaires as in Experiment 1, including a demographic and health questionnaire, the Autism Quotient questionnaire ($M = 18.08$, $SD = 6.48$; AQ scores did not significantly differ between Experiments 1 and 2; $t(98) = -1.68$, $p = 0.096$), and the Oldfield handedness inventory ($M = 72.22$, $SD = 50.57$). Note that on our Preregistration, we also stated that we planned to collect participant responses to the Social Responsiveness Scale (Constantino et al., 2007). However, this questionnaire was omitted due to lack of time in the testing session.

Reaction Time Data Analysis

The same reaction time data analysis procedure was followed in Experiment 2 as that outlined in Experiment 1 for the latency data. Behavioural response times faster than 80 ms were discarded from the analyses, which led to 0.07% of the data being removed. The data were modelled using linear mixed-effects models in R. All predictors in the mixed-effects model were mean-centred. Outliers were removed from the model using the ‘romr.fnc’ function in R, which removed an additional 2.43% of data. No violations of linearity, homoscedasticity, or normality were detected. The final, best-fitting model was:

$$\begin{aligned} \text{Log(Latency)} \sim & \text{Autistic Traits} * \text{Motion} * \text{Figure} + \text{SOA} + \text{Target Position} + \\ & (1 + \text{Motion} * \text{Figure} + \text{SOA} * \text{Position} | \text{Participant}) \end{aligned}$$

Pupillometry Data Analysis

The same pupil data analysis procedure was followed in Experiment 2 as in Experiment 1.

Results

Reaction Time Results

The results from the mixed-effects model (Figure 3B; Table 1.2) revealed that, similar to the results from Experiment 1, participants took longer to disengage their attention from natural motion compared to machine-like motion, as demonstrated by a main effect of Motion. Again, we found that participants were faster to disengage from the centrally presented stimulus at the 3000 ms SOA compared to the 2500 ms SOA. No other significant main effects or interactions were found.

Pupil Results

As in Experiment 1, the type of figure reliably predicted pupil size in Experiment 2 (Figure 4B and D). In other words, participants showed a greater increase in pupil size when viewing videos of human bodies compared to control figures from 220 – 510 ms. From 420 – 2500 ms, participants showed a greater increase in pupil size to videos of natural compared to machine-like motion. Further, as in Experiment 1, a significant interaction emerged between Motion and Figure from 1100 – 2500 ms. This interaction demonstrated that the difference in pupil size was larger between the two control figures than between the human bodies.

Figure 4. (A) The change in pupil size across time, for each of the four stimulus categories in Experiment 1 and (C) in Experiment 2. In panels A and C, the shaded areas represent ± 1 SE, and the vertical dashed lines indicate that the data from 220 ms were included in the mixed-effects model. The horizontal lines indicate significant main effects or interactions ($t > 2$), as calculated by the mixed-effects models. (B) Changes in pupil size during 750 – 1000 ms for Experiment 1 and (D) for Experiment 2. Error bars represent the 95% confidence intervals; all pupil size changes are reported in arbitrary units (a.u.), as discussed under the ‘Apparatus’ section for Experiment 1.

Summary

Participants took longer to disengage from videos of natural versus machine-like motion in the attentional disengagement task, and demonstrated greater pupil dilation for human than for control figures between 220 – 510 ms, and for natural versus machine motion from 420 ms. We replicated the significant interaction between Motion and Figure, whereby greater differences in pupil size emerged between the control figures than human bodies. As before, we found no relationship between reduced attentional engagement and arousal when participants reporting more autistic traits viewed naturalistic motion.

Discussion

Across two experiments, participants detected peripherally presented targets more slowly when watching an agent moving in a biologically plausible way, indicating that this stimulus type leads to greater attentional engagement. This concurs with previously published reports that attention is drawn by biological motion (Fox & McDaniel, 1982) and by other social stimuli, such as faces displaying direct gaze (Senju & Hasegawa, 2005). These results suggest that biological motion, quickly and reflexively, captures our attention and sustains it. To our knowledge, this is the first study to demonstrate that visual attention is more engaged by naturalistic body motion compared to other, less socially relevant motion.

Based on previous findings, we predicted that individuals reporting more autistic traits would engage less with natural motion, however, we found no evidence to support this. The range of AQ scores reported by our two participant samples in Experiments 1 (range: 3 – 28, median = 15) and 2 (range: 8 – 33, median = 17.5) was

limited, with most participants scoring towards the lower end of the distribution. While differences in attentional engagement with social stimuli may emerge at the more extreme ends of the AQ distribution, other studies have also failed to identify a relationship between social attention and autistic traits (Freeth, Foulsham, & Kingstone, 2013). Thus, it remains unclear whether reported autistic traits, or indeed an ASD diagnosis, affects attentional engagement with socially-relevant motion cues. Future studies should recruit both TD participants and those with a clinical ASD diagnosis to further explore this relationship.

We also found a main effect of SOA in both experiments. Participants disengaged attention more slowly from the central stimulus at the 2500 ms compared to the 3000 ms SOA, in accordance with previous literature (Azarian et al., 2016; Senju et al., 2005). Future work could test the possibility that participants are still fully engaged with the videos at shorter SOAs, but begin to disengage at longer SOAs, leading to faster disengagement.

As hypothesised, across both experiments increases in pupil size were greater in response to naturalistic than to mechanistic motion. Sepeta and colleagues (2012) reported participants have greater pupil dilation when viewing images of happy faces showing direct compared to averted gaze. Our findings are the first to show that it is not only social stimuli that signal imminent social engagement, such as faces with direct gaze, that we find rewarding, but that other social stimuli, such as bodies moving biologically, also induce autonomic changes. Recently, Williams and Cross (2018) demonstrated that participants were willing to exert more effort to view videos of human than mechanical motion, further reinforcing the reward value of this type of stimulus. The present findings corroborate this previous work and contribute significant new insights to our understanding of social motivation in the typical

population, supporting the notion that the human body moving in a familiar way is a rewarding stimulus.

Furthermore, in both experiments, we demonstrated a significant interaction between motion and figure, whereby participants showed greater pupil dilation when viewing natural versus machine-like motion. However, later in the time course, this pupil size difference became greater between the control figures than the human bodies. The reasons for this unexpected interaction remain unclear. These findings also contrast with our latency and RT data, which demonstrate that the difference in RT between the two motion types is greater between the human bodies than the control figures. However, this finding might be partly due to the novelty of the control figure moving biologically. Our attention is reflexively captured by living beings that move similarly to us (Simion, Regolin, & Bulf, 2008); thus, the novelty of an unexpected figure moving in human ways could be particularly arousing. For example, the uncanny valley hypothesis (Mori, 1970) suggests that very human-like, non-human agents are perceived as eerie, and even more so when they are moving. Therefore, the naturalistically-moving control figures used here might have increased participants' arousal due to their perceived eeriness, or violated participants' predictions of how a non-human control figure should move (c.f., Cross et al., 2012; Saygin et al., 2012). Further research is required to test this explanation, and to explain why the human body moving in a mechanical way (the other mismatch between form and motion) did not capture attention to the same degree.

Taken together, these results complement and extend the existing social motivation literature. This is the first study to demonstrate that human body motion engages participants' attention more than machine-like motion does, and to associate this with changes in autonomic arousal, further supporting the notion that we value

biological motion as a rewarding stimulus. Our findings were less conclusive concerning the hypothesised relationship between autistic traits and reduced social motivation, as demonstrated by our eye-tracking measures. Further research involving both TD participants and those with an ASD diagnosis will help to elucidate the social reward value of biological motion among individuals across the spectrum of social abilities.

Open Science Statement:

Experiment 1 was not formally preregistered; the preregistration for Experiment 2 is available at <https://aspredicted.org/kb9p8.pdf>. De-identified data for both experiments along with the data analysis scripts are available at <https://tinyurl.com/ycgeco4p>

Author Contributions

E. H. Williams & E. S. Cross developed the study concept. All authors contributed to the study design. Testing and data collection were performed by E. H. Williams. E. H. Williams performed the data analysis and interpretation with feedback from F. Cristino and E. S. Cross. E. H. Williams drafted the manuscript and F. Cristino and E. S. Cross provided critical revisions. All authors approved the final version of the manuscript for submission.

References

Alegria, J., & Noirot, E. (1978). Neonate orientation behaviour towards human voice. *International Journal of Behavioral Development*, 1(4), 291-312.

- Azarian, B., Esser, E. G., & Peterson, M. S. (2016). Evidence from the eyes: Threatening postures hold attention. *Psychonomic bulletin & review*, 23(3), 764-770.
- Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of memory and language*, 59(4), 390-412.
- Baayen, R. H., & Milin, P. (2010). Analyzing reaction times. *International Journal of Psychological Research*, 3(2), 12-28.
- Bardi, L., Regolin, L., & Simion, F. (2011). Biological motion preference in humans at birth: role of dynamic and configural properties. *Developmental science*, 14(2), 353-359.
- 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.
- Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of memory and language*, 68(3), 255-278.
- Bates, D. (2006). *Lmer, p-values, and all that*. Retrieved from <https://stat.ethz.ch/pipermail/r-help/2006-May/094765.html>
- Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67, 1-48
- Belopolsky, A. V., Devue, C., & Theeuwes, J. (2011). Angry faces hold the eyes. *Visual Cognition*, 19, 27-36. DOI:10.1080/13506285.2010.536186

- Chevallier, C., Kohls, G., Troiani, V., Brodtkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in cognitive sciences*, 16(4), 231-239.
- Cross, E. S., Liepelt, R., de C. Hamilton, A. F., Parkinson, J., Ramsey, R., Stadler, W., & Prinz, W. (2012). Robotic movement preferentially engages the action observation network. *Human brain mapping*, 33(9), 2238-2254.
- Dawson, G., Meltzoff, A. N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of autism and developmental disorders*, 28(6), 479-485.
- Dubey, I., Ropar, D., & de C Hamilton, A. F. (2015). Measuring the value of social engagement in adults with and without autism. *Molecular autism*, 6(1), 35.
- Ellis, C. J. (1981). The pupillary light reflex in normal subjects. *British Journal of Ophthalmology*, 65(11), 754-759.
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39, 175-191.
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41, 1149-1160.
- Fletcher-Watson, S., Findlay, J. M., Leekam, S. R., & Benson, V. (2008). Rapid detection of person information in a naturalistic scene. *Perception*, 37, 571-583. DOI: 10.1068/p5705
- Fox, R., & McDaniel, C. (1982). The perception of biological motion by human infants. *Science*, 218(4571), 486-487.

- Freeth, M., Foulsham, T., & Kingstone, A. (2013). What affects social attention? Social presence, eye contact and autistic traits. *PloS one*, 8(1), e53286. DOI: 10.1371/journal.pone.0053286
- Frith, U., & Frith, C. (2010). The social brain: allowing humans to boldly go where no other species has been. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 365(1537), 165-176. DOI: 10.1098/rstb.2009.0160
- Kain, M. P., Bolker, B. M., & McCoy, M. W. (2015). A practical guide and power analysis for GLMMs: detecting among treatment variation in random effects. *PeerJ*, 3, e1226.
- Kikuchi, Y., Senju, A., Hasegawa, T., Tojo, Y., & Osanai, H. (2013). The effect of spatial frequency and face inversion on facial expression processing in children with autism spectrum disorder. *Japanese Psychological Research*, 55(2), 118-130.
- Klin, A., Lin, D. J., Gorrindo, P., Ramsay, G., & Jones, W. (2009). Two-year-olds with autism orient to non-social contingencies rather than biological motion. *Nature*, 459(7244), 257-261.
- Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2015). Package ‘lmerTest’. *R package version*, 2(0).
- Mathôt, S., Fabius, J., Van Heusden, E., & Van der Stigchel, S. (2018). Safe and sensible preprocessing and baseline correction of pupil-size data. *Behavior research methods*, 1-13.
- Mathôt, S., van der Linden, L., Grainger, J., & Vitu, F. (2015). The pupillary light response reflects eye-movement preparation. *Journal of Experimental Psychology: Human Perception and Performance*, 41(1), 28.

- Mathôt, S., Grainger, J., & Strijkers, K. (2017). Pupillary responses to words that convey a sense of brightness or darkness. *Psychological science*, 28(8), 1116-1124.
- Mori, M. (1970). The uncanny valley. *Energy*, 7(4), 33-35.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9(1), 97-113.
- Saygin, A. P., Chaminade, T., Ishiguro, H., Driver, J., & Frith, C. (2011). The thing that should not be: predictive coding and the uncanny valley in perceiving human and humanoid robot actions. *Social cognitive and affective neuroscience*, 7(4), 413-422.
- Senju, A., & Hasegawa, T. (2005). Direct gaze captures visuospatial attention. *Visual cognition*, 12(1), 127-144.
- Sepeta, L., Tsuchiya, N., Davies, M. S., Sigman, M., Bookheimer, S. Y., & Dapretto, M. (2012). Abnormal social reward processing in autism as indexed by pupillary responses to happy faces. *Journal of neurodevelopmental disorders*, 4(1), 17.
- Simion, F., Regolin, L., & Bulf, H. (2008). A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Sciences*, 105(2), 809-813. DOI: 10.1073/pnas.0707021105.
- Sirois, S., & Brisson, J. (2014). Pupillometry. *Wiley Interdisciplinary Reviews: Cognitive Science*, 5(6), 679-692.
- Tremblay, A., & Ransijn, J. (2015). Package 'LMERConvenienceFunctions'.
- Valenza, E., Simion, F., Cassia, V. M., & Umiltà, C. (1996). Face preference at birth. *Journal of experimental psychology: Human Perception and Performance*, 22(4), 892.

- Williams, E. H., & Cross, E. S. (2018). Decreased reward value of biological motion among individuals with autistic traits. *Cognition*, *171*, 1-9.
- Woodhouse, J. M. (1975). The effect of pupil size on grating detection at various contrast levels. *Vision research*, *15*(6), 645-648.