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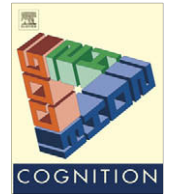
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## Anticipating intentional actions: The effect of eye gaze direction on the judgment of head rotation

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### ABSTRACT

Using a representational momentum paradigm, this study investigated the hypothesis that judgments of how far another agent's head has rotated are influenced by the perceived gaze direction of the head. Participants observed a video-clip of a face rotating 60° towards them starting from the left or right profile view. The gaze direction of the face was either congruent with, ahead of, or lagging behind the angle of rotation. Following this, two static faces, at varying angles of rotation with respect to the end-point angle of the face in the video-clip, were presented simultaneously. The task of the participants was to decide which of the two heads was at an angle best resembling the angle of the end-point of the moving face. The critical test condition consisted of one test face oriented at 10° before, and the other at 10° after the end-point. The 'lagging behind' gaze condition elicited a significant underestimation of the rotation compared to the 'congruent' and 'ahead' gaze conditions. Participants did not exhibit similar biases when judging the rotation of several non-face control stimuli with visual features that mimicked different aspects of gaze direction. The findings suggest that when the gaze direction of a perceived agent is incongruent with the direction of the agent's head motion observers automatically utilise this discrepancy to adjust their inferences about the agent's intended heading direction.

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### 1. Introduction

When observing an object in motion, the causes of its motion are inferred depending on the nature of the object. In the case of non-agentive objects, which are inanimate and incapable of intentionality, the motion is assumed to be the product of physical laws. To understand non-agentive motion, a process of systemising is employed to find the underlying principles that cause and constrain the object's motion. In the case of agentive objects, which are animate and possess intentionality, motion is also subject to such factors, but in addition can be self-propelled and be motivated by the goals and objectives of the agent (Lieberman, Gaunt, Gilbert, & Trope, 2002). To understand these

latter aspects of agentive motion, a process of empathising is employed (including theory of mind) to attribute intentions, emotions and mental states (Baron-Cohen, 1995). The dichotomy can be seen when watching someone kick a football. The player has certain objectives in doing so (to score a goal or pass to another player) and so modifies the kick accordingly to achieve a particular trajectory. The movement of the player is therefore understood in terms of his/her intentions. However, the behaviour of the ball is not interpreted in such terms, the trajectory of which is subject to systematic physical laws (e.g. force of kick, gravity, and wind). Baron-Cohen (2002, 2006) has proposed that an individual's propensity to engage these two cognitive processes may be related, with those individuals showing greater empathising skills more likely to be poorer in systemising, and vice versa.

Attributing intentionality to agentive motion engages both automatic/involuntary and controlled systems in the

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observer (Lieberman et al., 2002). Involuntary attributions are based on the perception of simple bodily cues such as gaze direction, articulation of body parts, and the environmental context (Jellema & Perrett, 2002, 2005). Its subconscious nature ensures the inferences are made quickly and effectively, which reflects the evolutionary pressures placed on the ability to process large amounts of dynamic social information (Dunbar, 1998).

Perceived gaze direction, in conjunction with head and torso direction, allows the observer (i.e. the participant in the experiment) to infer what the focus of an agent (i.e. the experimental stimulus) is (Perrett, 1999), which impacts on the observer's own behaviour. Primates (Tomasello, Call, & Hare, 1998) and a variety of non-primates (Emery, 2005) have been shown to modify their behaviour in response to the gaze direction of conspecifics. The current study focuses on the role of gaze and head cues in anticipating others' future actions. As attention is often fixated on the goal of an action, discerning the direction of gaze will generally allow the observer to discriminate between actions performed either intentionally or accidentally (Jellema, Baker, Wicker, & Perrett, 2000), although there exist notable exceptions to this rule. One can then form expectancies as to how the action will most likely unfold in the immediate future (Perrett, Xiao, Jellema, Barracough, & Oram, 2006). Furthermore, knowing what another person is looking at constitutes the basis of ToM (Baron-Cohen, 1995; Charman et al., 2000).

The social significance of an averted gaze derives not just from its orientation in relation to the observer, but also from the agent's own line of regard. Gaze direction appears to be referenced initially in relation to the agent's frame of reference, and only then in relation to the observer (Bayliss, di Pellegrino, & Tipper, 2004; Bayliss & Tipper, 2006). This has implications for social interactions. An averted gaze will maximally elicit reflexive orienting of an observer's spatial attention to the gazed-at location if gaze and head are incongruently oriented, while the effect is less strong when gaze and head are congruently aligned (Hietanen, 1999; Hietanen, 2002; Langton & Bruce, 1999). This is probably due to the fact that an incongruent gaze-head alignment forms a conspicuous cue suggesting that a stimulus has caught the person's attention in the immediate past (Bertenthal & Von Hofsten, 1998). In contrast, a congruent alignment does not necessarily imply that attention is directed at a specific stimulus.

These social inferences are supported by dedicated neural substrates within the visual system, most noticeably the superior temporal sulcus (STS). The STS is implicated in the processing of biological motion and bodily actions (Allison, Puce, & McCarthy, 2000) and single cell studies of the Macaque have revealed STS cell populations selectively responsive to specific directions of gaze, head and torso orientation, either in isolation or in conjunction (Perrett, Hietanen, Oram, & Benson, 1992). Such coding can be either object-centred or viewer-centred (Jellema & Perrett, 2006). The discovery of STS cell populations coding for actions in relation to contextual cues rather than for actions *per se* (Jellema, Maassen, & Perrett, 2004; Jellema et al., 2000; Perrett, 1999), and of cell populations that are implicated in deducing the end-point of an action sequence

based on the immediately preceding movements (Jellema & Perrett, 2003b), have contributed to the idea that the STS is involved in representing goal-directed and intentional actions (Jellema & Perrett, 2005; Pelphrey, Morris, Michelich, Allison, & McCarthy, 2005; Saxe, Xiao, Kovacs, Perrett, & Kanwisher, 2004).

### *1.1. Memory displacement as a measure of causal attributions made to agentive and non-agentive motion*

The processing of gaze direction may support inferences about the future course or the goal of agentive motion. As such it can play a critical role in the attribution of intentionality. The reflexive nature of such attributions are difficult to detect and measure, and may only be verified by their effects on performance in an indirect task. Representational momentum (RM) tasks offer one way to study these processes. Due to RM, the observer's memory for the final position of a moving target is typically displaced further along the observed trajectory. This phenomenon results from the observer's inferences regarding the physical dynamics of the movement, and is hypothesized to reflect an anticipatory function (Finke & Freyd, 1985; Freyd & Finke, 1984). The extent of the memory displacement is subject to varying physical causes (e.g. gravity) and constraints (e.g. friction) acting upon the object's motion (Hubbard, 1995). The displacement occurs even for static images of implied motion (Freyd, 1983). Importantly, the effect is subject to conceptual knowledge the observer has about the nature of the object (Vinson & Reed, 2002).

If the source of the object's motion is implied to result from a collision with another moving object, the discrepancy between the remembered and veridical final positions may be less than if just the moving target is presented. Therefore, if the object's motion is self-propelled, it is subject to a greater anticipatory bias than if it has no intrinsic means of movement (Hubbard, Blessum, & Ruppel, 2001; Hubbard & Favretto, 2003; Hubbard & Ruppel, 2002). Such self-propulsion is characteristic of biological motion, and is one of several factors that infants are sensitive to when distinguishing between animate and inanimate objects (Johnson, 2003). Indeed, biological motion has been shown to be subject to anticipatory displacements (Daems & Verfaillie, 1999; Verfaillie & Daems, 2002). In the case of agentive motion, cues indicative of the causes of the motion can be both physical and intentional. There has been little research explicitly investigating whether displacement of agentive motion is subject to the involuntary processing of social cues conveying the goal of the action, though several studies report related effects. For example, Freyd and Miller (1992) observed a greater displacement for a schematic animal moving forwards in the direction it was looking than moving backwards, though Thornton and Hayes (2004) dispute a role for social signals in RM. Lobmaier, Fischer, and Schwaninger (2006) reported that the perceived point to which another's gaze is fixated is displaced toward the location of environmental objects. This suggests that a role for intentional attribution in RM is worthy of investigation.

## 1.2. The current study

The aim of the current study was to assess if involuntary processing of social cues conveying the goal of an action and the state of mind of the agent contributes to the anticipation of the agent's behaviour in the immediate future. More specifically, whether the memory displacement in the case of an agent's self-propelled motion was subject not only to the physical invariants acting upon object motion, but also to the observer's inferences about the intentions and motivations underpinning the motion. A new task was introduced that was specifically designed to measure the observer's involuntary inference of an agent's intention on the basis of their gaze direction. The task required participants to observe a video-clip starting with a human face at a profile view ( $90^\circ$ ), which rotates towards them, stops at  $30^\circ$  (full frontal view is  $0^\circ$ ) and immediately disappears. Next, two test faces were shown, with face angles at different orientations selected from the observed and extrapolated trajectory. Participants had to select the test face with the angle they think best resembled the face angle in the last frame of the clip. The crucial manipulation was that the gaze direction of the head in the clip was varied: it was either lagging behind, in advance of, or congruent with, the head rotation. When gaze is ahead of head orientation, there should be a relative overestimation due to the perceived intention to carry on in that direction, and when gaze is lagging behind head rotation, there should be a relative underestimation due to perceived unwillingness or hesitation to engage in further rotation.

Several control stimuli that rotated in an identical way were also tested. These contained attributes that were comparable to the changes in the appearance of the eyes in the three gaze conditions, however the inanimate look was expected to elicit no sense of intentionality. In Experiment 1, these features were oriented vertically within the non-agentive stimulus so as to prevent the perception of a face-like configuration and maintain the non-agentive nature. In Experiment 2, these features were placed in a horizontal orientation to investigate if estimations of object rotation varied when the visual features of the non-agentive stimulus were oriented to reflect those of a face-like configuration (but without creating the sense of an animate object). In an additional condition, the equivalent 'gaze' features were replaced by arrows, which possess spatial meaning, and which could be related to the direction of object rotation in much the same way as gaze direction. The apparent self-propelled motion of the non-agentive stimuli should exhibit RM due to assumptions regarding its momentum, but this RM should not vary as a consequence of the manipulations designed to mimic the visual appearance of the gaze direction of the agentive stimulus. The results of these experiments confirmed the predictions, in that estimations of how far the agentive stimulus had rotated varied as a function of gaze direction, while no such variation was elicited by the equivalent conditions for the non-agentive stimuli. The assumption that agentive and non-agentive memory displacements evolved for different functions using different mechanisms is discussed.

## 2. Experiment 1

### 2.1. Method

#### 2.1.1. Participants

Twenty-eight undergraduate psychology students (27 females) with a mean age of 21.5 years ( $SD = 9.1$ ) from the University of Hull participated in Experiment 1 for course credit. All reported normal or corrected vision, and provided their written informed consent prior to the experiment.

#### 2.2. Stimuli

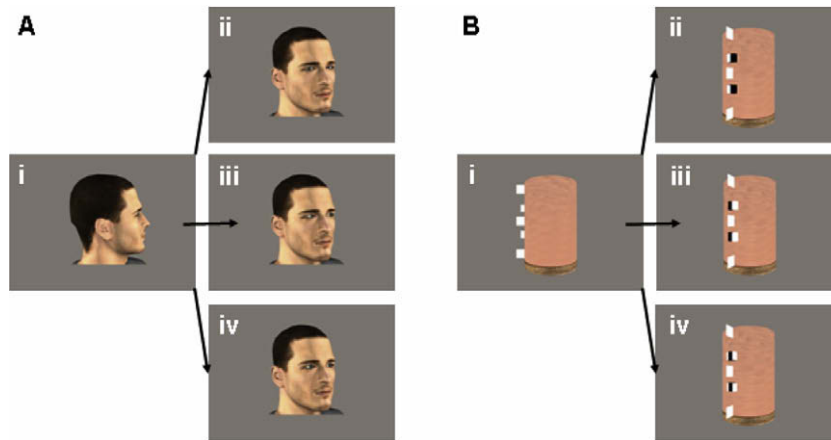
Stimuli were created using Poser 6 animation software (Curious Labs, Inc. & e-frontier, Inc). The stimuli were presented on a 21-inch monitor (100 Hz) using E-Prime software (Psychology Software Tools, Inc). Two stimulus conditions were created: agentive and non-agentive.

##### 2.2.1. Agentive stimuli

Two human agents used in the agentive stimulus condition were 'James' (male) and 'Jessi' (female). Their shoulders were oriented  $45^\circ$  away from the observer in the direction the agent was facing (left or right), and remained at that orientation throughout the stimulus presentation. The head always rotated  $60^\circ$  toward the observer, starting from a  $90^\circ$  deviation (i.e. full profile view) and ending at a  $30^\circ$  deviation from full frontal view (Fig. 1A). The motion was induced through rapid presentation (40 ms/image) of 16 images (640 ms in total, at a rate of  $93.8^\circ$  per second), depicting the object progressively rotating along its vertical axis at  $4^\circ$  interpolations. The height of the subtended angle was  $7.0^\circ$  for 'Jessi', and  $6.5^\circ$  for 'James'. As the face rotated, the width of the stimuli varied from  $5.1^\circ$  to  $4.0^\circ$  for 'Jessi', and  $5.7^\circ$  to  $5.1^\circ$  for 'James'. The background colour was grey. The crucial manipulation consisted of varying the gaze direction of the agent relative to the direction of the head movement: in 1/3 of the trials the gaze was directed  $20^\circ$  in advance of the head direction (gaze-ahead condition), in 1/3 of the trials the gaze direction was the same as the head direction (gaze congruent condition), and in 1/3 of the trials the gaze direction was  $20^\circ$  lagging behind the head direction (gaze-lagging condition; Fig. 1A).

##### 2.2.2. Non-agentive stimuli

The non-agentive stimulus consisted of a cylinder of comparable size, colour and texture to the agentive stimulus (Fig. 1B). The subtended angle of the stimulus height was  $6.3^\circ$ , while the subtended angle of the stimulus width varied from  $4.3^\circ$  to  $3.3^\circ$ . It was placed on a disc of the same diameter as the cylinder (but with different texture), which provided a base upon which the object rotated analogous to how the head rotated on the shoulders in the agentive stimulus. The three white fins protruding from the cylinder provided additional cues to the degree of rotation in the same way as the chin and nose of the agentive stimulus did. Placed in between the three fins were two white cubes half submerged into the cylinder. Half of the surface area of the cubes was coloured black, this area was either on the



**Fig. 1.** The three gaze conditions of the agentive (A) and non-agentive (B) stimuli. The starting point was a profile view (90°), facing either to the right (Ai) or left (Bi). The end-points were at 30° from full frontal view in the gaze-ahead (ii), gaze-lagging behind (iii) and gaze congruent (iv) conditions.

left, right or centre of the cube. This pattern of colouration mimicked the iris/sclera configuration in the three gaze conditions and the nature of rotation was identical to that of the agentive stimulus (Fig. 1B). In addition to controlling for the effect of perceived intentionality on memory displacement, the non-agentive stimulus also served to control for a possible 'low-level' contribution of the horizontal shift of the pupil location to memory displacement. In this respect it should be noted that the equivalent of the gaze-manipulation in the non-agentive condition was more conspicuous than the real eye gaze stimulus, as the size of the black and white cube was considerably larger than that of the eyes while it was also more prominently positioned. Therefore, if it was the low-level horizontal shift in pupil position *per se* which caused the displacement in the agentive stimulus, then certainly the non-agentive stimulus should evoke displacement as a function of the equivalent of the gaze direction manipulations.

### 2.2.3. Test stimuli

To measure the remembered position of rotation, participants compared a pair of test stimuli with the end-point of the video-clip (which was always at 30°, left or right). The test stimuli consisted of two still images of the rotating agentive/non-agentive objects. They were shown simultaneously, side by side, each oriented at a different angle. One was oriented before the end-point (i.e. at an orientation encompassed within the rotation trajectory of the moving stimulus), the other after that point (i.e. extrapolated beyond the end-point of the moving stimulus further along the trajectory). One of the choices always deviated by 10° either before ('-') or after ('+') the stopping angle of the rotating stimulus, while the other choice deviated by 10°, 20° or 40° in the opposite direction. This created five test stimulus levels (-40°/+10°, -20°/+10°, -10°/+10°, -10°/+20°, -10°/+40°; left/right positions on the screen were counterbalanced).

In symmetrical experimental trials, both test choices deviated 10° from the stopping angle (-10°/+10°,

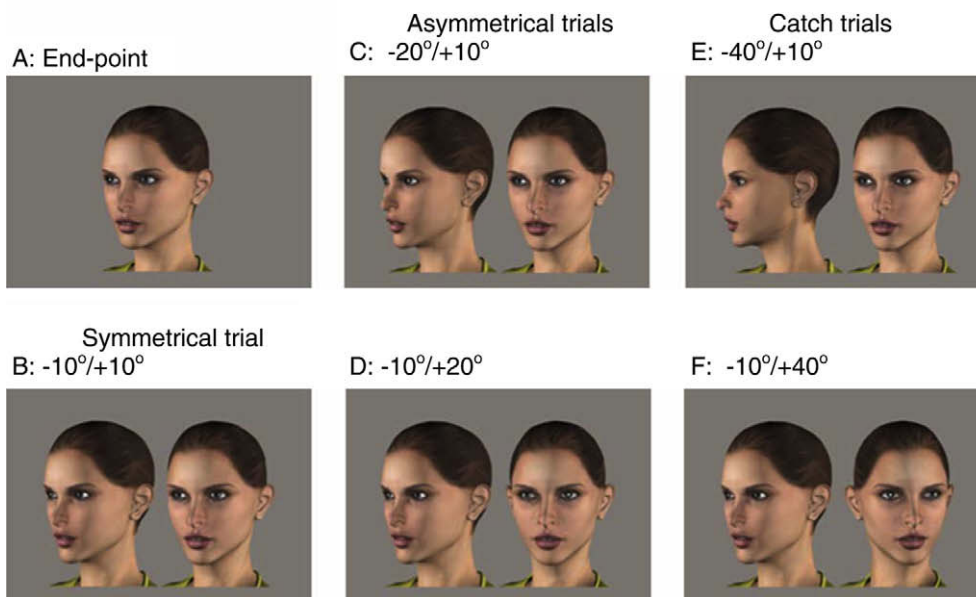
Fig. 2B). For these trials there was no correct answer. If no memory displacement occurs, participants would be no more likely to choose the 'before' or 'after' option, yielding a 50/50 split on average. Occurrence of a memory displacement, however, would result in a bias for one choice over the other: a bias toward choosing the 'after' choice would be indicative of overestimation and a bias toward choosing the 'before' choice of underestimation.

In the asymmetrical experimental trials, the remaining test choice was oriented 20° in the opposite direction. In these trials either the 'before' choice (-10°/+20°) or the 'after' choice (-20°/+10°) was correct (Fig. 2C and D). The aim was to see if gaze direction could induce errors in the presence of a correct answer. Although a weaker effect of gaze direction is expected in asymmetrical compared to symmetrical experimental trials, an effect of gaze direction would strengthen the hypothesis should it be present.

In the final two levels, the asymmetry was increased even further by pairing the 10° choice with a 40° choice (Fig. 2E and F). The correct answers, either 'before' (-10°/+40°) or 'after' (-40°/+10°), could easily be given and ceiling performance was expected. Incorrect answers here could be attributed to insufficient attention being paid to the task, so these were designated as catch trials and performance on these trials was used as a selection criterion.

The height of the test stimuli were the same as for the rotating stimuli. The two test stimuli were positioned in the centre of the screen, at equal distances at either side of fixation. The width and distance from the centre varied according to the test stimulus used. The subtended width between the outer edges of the two test stimuli was between 16.2° and 18.4°, with the inner edge of each between 0.8° and 1.7° from the centre, and outer edge between 8.4° and 9.6° from the centre. In the test stimuli, the gaze direction (or its equivalent) was always congruent with the angle of the head (or the control object). Left/right screen positions of the 'before' and 'after' choices were counterbalanced across trials.





**Fig. 2.** Examples of test stimuli. (A) The end-point position, at an angle  $30^\circ$  from full frontal view, of a head in the video-clip that started its rotation from a left profile view. (B) Symmetrical experimental trials where neither choice is more similar to the end-point of the moving stimulus. (C–D) Asymmetrical experimental trials where the ‘after’ (C) and ‘before’ (D) response was correct. (E–F) Catch trials in which the ‘after’ (E) and ‘before’ (F) response was correct.

#### 2.2.4. Procedure

Participants sat 60 cm from the computer monitor. They were instructed they would see a face or object rotate along the vertical axis towards them, and that this would be followed by two still faces or objects. Their task was to indicate by pressing one of two keys on the keyboard which of the two faces/objects was at an angle most similar to the final angle of the moving face/object. The ‘J’ and ‘L’ keys were used, labeled as ‘left’ and ‘right’ respectively. No mention of gaze direction was made. It was stressed that accuracy was more important than speed of response, but that answers were to be made within a few seconds.

Participants completed 12 practice trials representative of the range of manipulations. This was followed by the experimental session which contained 2 blocks of 108 trials (216 trials in total). In one block, a retention interval of 1000 ms was placed in between the rotating stimulus and the test stimulus. In the other block, the retention interval was absent. The presentation order of the two blocks was counterbalanced across participants.

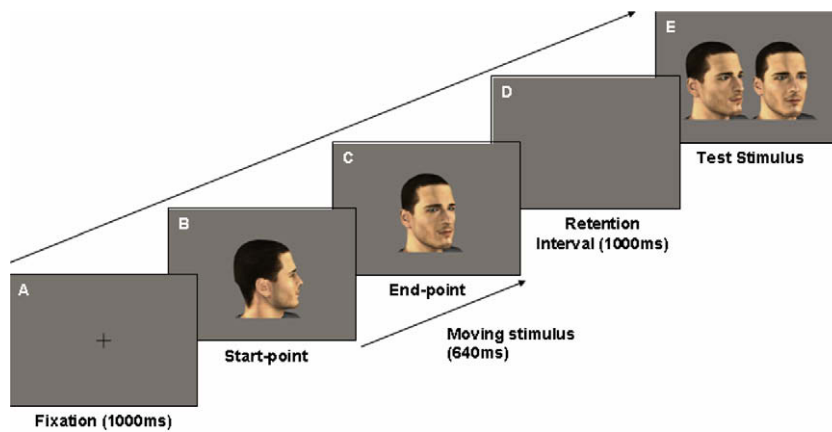
The choice of retention interval length was based on studies using a similar method of data analysis. For example, Finke and Freyd (1985) varied the retention interval between 500 and 2000 ms and found the magnitude of errors to peak within 500 ms and only to slowly decay thereafter. Freyd and Finke (1984) used retention intervals of 250, 500 and 750 ms and observed displacement at each. In contrast, a study by Freyd and Johnson (1987) found the displacement effect to peak at 250–300 ms and to rapidly decline thereafter. However, this latter study used a different methodology in which the data was subjected to a quadratic regression. It was therefore expected that in this study a displacement effect would not rapidly

diminish after 250–300 ms and would still be evident at a 1000 ms retention interval.

Each block contained three different types of trials: symmetrical experimental trials ( $n = 36$ , 12 ‘James’, 12 ‘Jessie’, 12 non-agentive), asymmetrical experimental trials ( $n = 36$ , 12 ‘James’, 12 ‘Jessie’, 12 non-agentive; for half of each group the correct answer was before the end-point, i.e.  $-10^\circ/+20^\circ$ , for the other half after the end-point, i.e.  $-20^\circ/+10^\circ$ ), and catch trials ( $n = 36$ , 12 ‘James’, 12 ‘Jessie’, 12 non-agentive; for half of each group the correct answer was before the end-point, i.e.  $-10^\circ/+40^\circ$ , for the other half after the end-point, i.e.  $-40^\circ/+10^\circ$ ). The rotation started either from the left profile (anti-clockwise) or from the right profile (clockwise), with an equal number of trials for each direction.

Each trial began with a 1000 ms fixation cross at the centre of the screen. This was followed by a rotating face/object (duration 640 ms). In trials with a retention interval, the rotating stimulus was followed by a blank screen of identical colour to the background of the rotating stimulus for 1000 ms. Next, the test stimuli were displayed, and remained on screen until a response was made. In trials without a retention interval, the test stimulus was presented immediately after the rotating stimulus. The inter-trial-interval was 1000 ms. Fig. 3 shows an example of a trial.

After completion of the experiment, the participants completed a feedback form. The purpose of this was to assess whether participants had been aware of the gaze-manipulation, to see how they experienced the control object, and to gauge what methods, if any, they used to complete the task. For example, they were asked to describe what they thought the rotating non-agentive stimulus was and why it was moving.



**Fig. 3.** Example of a trial. The trial started with a fixation cross (A), followed after 1000 ms by the moving stimulus (B–C). In half the trials, this was followed by a retention interval of 1000 ms duration (D), followed by the test stimulus (E). In the remaining trials, no retention interval was present, and the test stimulus followed immediately after the moving stimulus.

### 2.3. Results

#### 2.3.1. Data reduction

The overall error rate in the catch trials was 13.9% ( $SD = 9.1$ ). Participants whose mean error rate exceeded 20% were excluded from the analysis (6 participants), resulting in a final group of 22 participants. In addition, individual trials were removed if responses were made less than 250 ms after onset of the test stimulus or in excess of 2.5SD of each participant's mean reaction time. Of the remaining participants, 2.4% of trials were excluded in this way. On the basis of information provided on feedback forms completed following the experiment, no further participants were excluded.

#### 2.3.2. The effect of gaze on agentive and non-agentive motion

As one of the test heads was always shown at an angle before the stopping point, and the other at an angle after the stopping point, these two choices are referred to as the 'before' and 'after' choices for the sake of brevity. However, it should be noted that it was the participants' task to judge which of the two test heads most resembled the head at the stopping point in the video; it was not their task to make a judgment about whether the test head was 'before' and 'after' the video head. Trials in which the 'before' stimulus was judged as more similar to the stopping point were coded as '0', and those in which the 'after' stimulus was chosen were coded as '1'. The resulting

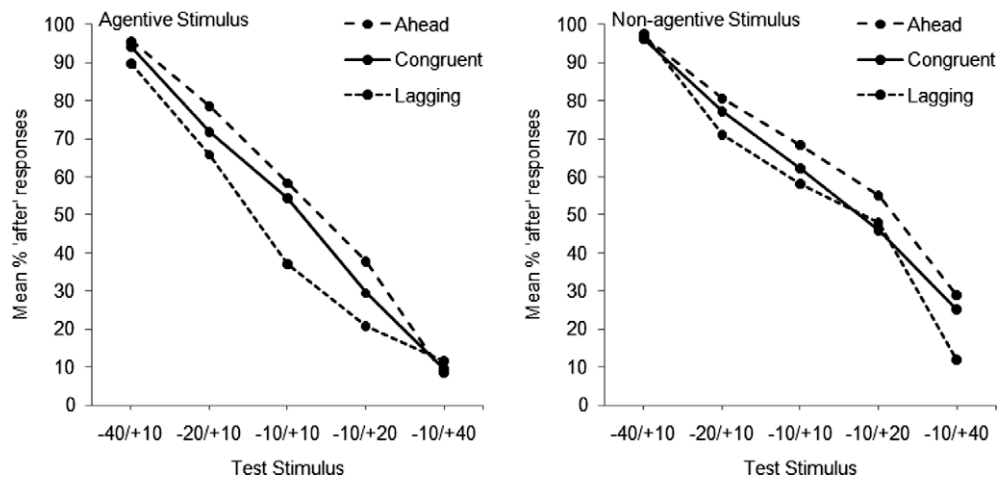
scores thus reflected the mean percentage of trials in which the 'after' test choice was judged as more similar to the stopping angle than the 'before' test choice. These values were entered into a repeated measures ANOVA with stimulus type (agentive vs. non-agentive), Retention interval (absent vs. present), Gaze direction (ahead vs. congruent vs. lagging behind) and Test stimulus ( $-20^\circ/+10^\circ$  vs.  $-10^\circ/+10^\circ$  vs.  $-10^\circ/+20^\circ$ ) entered as the main factors. Since the  $-40^\circ/+10^\circ$  and  $-10^\circ/+40^\circ$  conditions were used as a means to exclude participants, these were not included as levels in the test stimulus condition, although the data for these trials are presented in the tables and figures for the purpose of comparison (see Table 1 and Fig. 4).

As expected, there was a significant main effect of Test stimulus ( $F(2,42) = 157, p < .001, \eta_p^2 = .88$ ) with the percentage of 'after' choices decreasing as the similarity of the after choice to the moving stimulus' end-point decreased. There was no main effect of Retention interval ( $F(1,21) = .15, p = .704, \eta_p^2 = .007$ ). There was a main effect of stimulus type, with the non-agentive stimulus eliciting significantly more 'after' choices than the agentive stimulus ( $F(2,21) = 19.9, p < .001, \eta_p^2 = .49$ ), and a main effect of Gaze direction ( $F(2,42) = 13.3, p < .001, \eta_p^2 = .39$ ). There was a significant interaction between Gaze direction and stimulus type ( $F(2,42) = 3.84, p = .029, \eta_p^2 = .16$ ), and a significant interaction between stimulus type and Test stimulus ( $F(2,42) = 9.66, p < .001, \eta_p^2 = .315$ ). None of the other interactions were significant.

**Table 1**

Mean percentage of 'after' choices for each gaze direction across each level of test stimulus for the agentive and non-agentive stimuli. The SDs of the mean percentages are shown between brackets.

	Agentive stimulus			Non-agentive stimulus		
	Ahead	Congruent	Lagging	Ahead	Congruent	Lagging
$-40^\circ/+10^\circ$	95.7 (7.9)	94.2 (13.2)	89.7 (18.6)	96.9 (7.6)	96.2 (8.1)	97.7 (6.3)
$-20^\circ/+10^\circ$	78.6 (15.2)	71.8 (19.8)	65.8 (24.0)	80.6 (18.8)	77.1 (24.9)	71.1 (23.8)
$-10^\circ/+10^\circ$	58.3 (17.1)	54.4 (22.9)	37.2 (20.5)	68.4 (23.0)	62.3 (21.0)	58.2 (26.3)
$-10^\circ/+20^\circ$	37.8 (15.9)	29.6 (18.0)	20.9 (16.1)	55.0 (27.1)	45.8 (26.7)	48.1 (24.1)
$-10^\circ/+40^\circ$	8.3 (9.3)	9.6 (9.9)	11.6 (12.0)	28.8 (24.5)	25.2 (23.0)	11.9 (21.1)



**Fig. 4.** Mean percentage of 'after' choices for each gaze direction across the levels of the test stimulus for the agentive stimulus (left) and the non-agentive stimulus (right). Retention intervals were collapsed.

The crucial interaction between Gaze direction and stimulus type was investigated further by conducting one-way repeated measures ANOVAs with Gaze direction as the main effect for each stimulus type (agentive and non-agentive) and for each test stimulus level. Where a significant effect was found, paired sample *t*-tests between all three gaze conditions were conducted with a Bonferroni corrected *p*-value of .017 (0.05/3). In the symmetrical experimental trials, one sample *t*-tests were also conducted with a test value of 50% to test for a response bias indicative of representational momentum. These tests were two tailed when an effect of gaze was found, as both under and overestimation could be elicited. However, where no effect of gaze was present, only overestimation is expected, making a one-tailed test more appropriate.

**2.3.2.1. The agentive stimulus.** For the agentive stimulus, there was a significant main effect of gaze direction in each of the three test stimulus levels. In the  $-20^\circ/+10^\circ$  asymmetrical experimental trials ( $F(2,42) = 5.76$ ,  $p = .006$ ,  $\eta_p^2 = .22$ ), the gaze-ahead condition elicited significantly more 'after' choices than the gaze-lagging condition ( $t(21) = 3.71$ ,  $p = .001$ ). However, responses in the gaze congruent condition did not differ significantly from responses in either the gaze-ahead ( $t(21) = 1.86$ ,  $p = .08$ ) or gaze-lagging conditions ( $t(21) = 1.42$ ,  $p = .17$ ).

In the symmetrical experimental ( $-10^\circ/+10^\circ$ ) trials, ( $F(2,42) = 15.11$ ,  $p < .001$ ,  $\eta_p^2 = .42$ ), the gaze-lagging condition elicited significantly less 'after' choices than both the gaze-ahead ( $t(21) = 5.44$ ,  $p < .001$ ) and gaze congruent conditions ( $t(21) = 3.92$ ,  $p = .001$ ), the responses of which did not differ from each other ( $t(21) = .93$ ,  $p = .36$ ). Because of this difference, the one sample *t*-tests were conducted for each gaze direction condition ( $p = .017$ ), which showed only responses in the gaze-lagging condition to differ significantly from 50% ( $t(21) = 2.9$ ,  $p = .008$ ), whereas responses in the gaze-ahead ( $t(21) = 2.27$ ,  $p = .03$ ) and gaze congruent ( $t(21) = .95$ ,  $p = .36$ ) levels did not.

In the  $-10^\circ/+20^\circ$  asymmetrical experimental trials ( $F(2,42) = 8.77$ ,  $p = .001$ ,  $\eta_p^2 = .3$ ), the mean percentage of

'after' choices was significantly greater in the gaze-ahead condition than in the gaze congruent ( $t(21) = 2.63$ ,  $p = .016$ ) or gaze-lagging conditions ( $t(21) = 4.04$ ,  $p = .001$ ), between which responses did not differ significantly from each other ( $t(21) = 1.88$ ,  $p = .08$ ).

**2.3.2.2. The non-agentive stimulus.** For the non-agentive stimulus, there was no main effect of 'gaze' direction in any of the test stimulus levels. Because of this, the 'gaze' direction levels were collapsed in the symmetrical experimental trials for the one sample *t*-test. This showed that the mean percentage of 'after' choices (63.0%,  $SD = 48.3$ ) was significantly greater than the test value of 50% ( $t(21) = 3.4$ ,  $p = .002$ ).

For the interaction between stimulus type and test stimulus, one-way ANOVAs with stimulus type as a repeated measures factor show the non-agentive stimulus to elicit more 'after' choices in the  $-10^\circ/+10^\circ$  trials ( $F(1,21) = 10.31$ ,  $p = .004$ ,  $\eta_p^2 = .33$ ) and  $-10^\circ/+20^\circ$  trials ( $F(1,21) = 41.07$ ,  $p < .001$ ,  $\eta_p^2 = .66$ ), but not in the  $-20^\circ/+10^\circ$  trials ( $F(2,21) = 3.06$ ,  $p = .095$ ,  $\eta_p^2 = .13$ ). The different effects of gaze direction between the stimulus types can account for this interaction. The rotation of the agentive stimulus was underestimated in the gaze-lagging condition, whereas the non-agentive stimulus elicited overestimation irrespective of 'gaze' direction. A lower overall percentage of 'after' choices is therefore expected where the effect of gaze was strongest.

## 2.4. Discussion

The agentive and non-agentive nature of the stimuli produced different results. There was a significant overall effect of gaze direction for the agentive stimulus. That is, despite the stopping angle of the head being equivocal in all conditions, estimations of how far it had rotated were influenced by the direction of its gaze. Specifically, head rotations were underestimated when gaze was looking in the opposite direction of motion, as compared to looking straight ahead or in advance of head rotation. The equiva-



lent of the 'gaze' manipulation in the non-agentive condition had no such effect. In the non-agentive condition, estimations of the degree of rotation were the same irrespective of the visual appearance of the black and white cubes designed to mimic the relative positions of the pupil and sclera in the agentive condition. This is all the more remarkable as the black squares in the non-agentive condition were larger and considerably more pronounced than the pupils in the agentive condition. It supports the contention that the biases in estimating head rotation elicited by gaze direction are due to inferences made by the observer regarding the agent's intention to move further, or not to move further, in the specified direction, and are not due to the low-level visual appearance of the pupil shifting within the sclera.

However, whilst the black and white cubes of the non-agentive stimulus may have imitated the sclera/pupil positions of the eye, they failed to replicate other important aspects of gaze processing necessary for the inference of social significance. Firstly, the face presents a unique pattern of internal features, with the eyes occupying an important place within it (Barton, Zhao, & Keenan, 2003). Indeed, it is difficult to view a stimulus that possesses such a pattern without perceiving it as representing a face. The vertical orientation of the white cubes in the current study failed to replicate this distinctive configuration.

Secondly, the social significance of gaze direction depends on its spatial meaning, which is used by the observer to unambiguously determine where the other person is looking. This directional information is processed reflexively, as indicated by studies in which the detection of a target was facilitated if preceded by a centrally presented gaze directed at the target location, but not when directed elsewhere (Frischen, Bayliss, & Tipper, 2007; Ricciardelli, Bonfiglioli, Iani, Rubichi, & Nicoletti, 2007). Again, the non-agentive stimulus did not possess this quality and therefore the observer could not determine the 'direction'

of the manipulations in the same way as for the agentive stimulus. For these reasons, a second experiment was conducted with two new non-agentive stimuli devised to address these issues.

### 3. Experiment 2

#### 3.1. Method

##### 3.1.1. Participants

Thirty-three participants (27 females), with a mean age of 20.3 years (SD = 4.4 years), took part. All other information is the same as for Experiment 1.

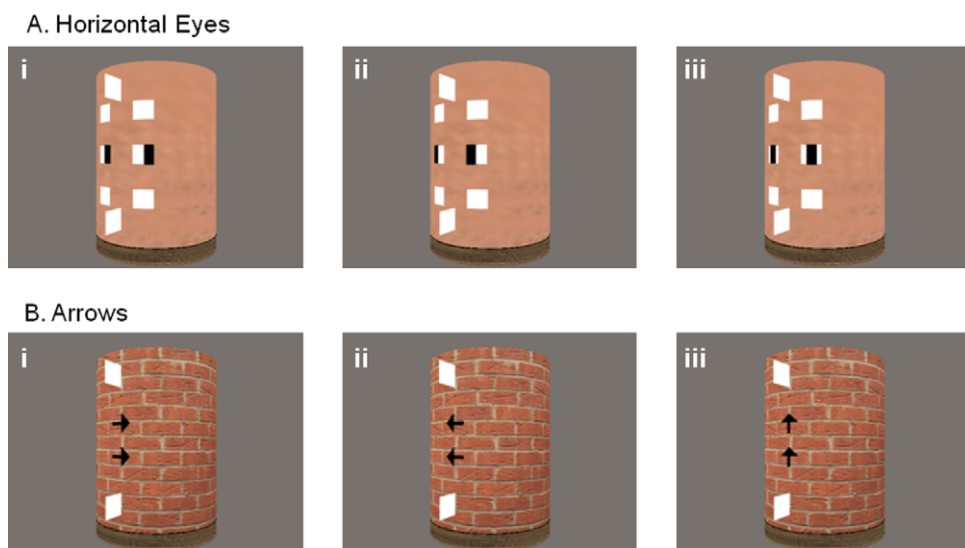
##### 3.1.2. Stimuli

Stimulus creation and presentation was the same as in Experiment 1.

**3.1.2.1. Horizontal 'eyes'.** The black and white cubes were placed in a horizontal orientation to reflect the position of the eyes in a face. However, as noted earlier, even the most rudimentary resemblance to a facial configuration is sufficient to evoke the perception of a face. In order to implement the design without creating the impression of a face, four additional white squares were introduced to disrupt the face-like configuration (Fig. 5A).

**3.1.2.2. Arrow 'eyes'.** The black and white cubes of Experiment 1 were replaced by two arrows. Arrows are a symbolic cue of spatial direction (Ricciardelli et al., 2007) and orient an observer's attention in a similar manner as gaze direction (Frischen et al., 2007). The surface was given a brick texture in order to reinforce the impression of a non-agentive object (Fig. 5B).

For both stimuli, these variable features were superimposed onto the surface of the stimulus rather than protruding from it, and the number of fins was reduced from three



**Fig. 5.** The two non-agentive stimuli used in Experiment 2. (A) The white cubes are oriented horizontally. (B) The white cubes are replaced by arrows. Examples show the end-points in each 'gaze' direction condition (i) 'gaze' ahead, (ii) 'gaze' lagging, and (iii) 'gaze' congruent. (For the arrows stimulus, an additional congruent condition was used with the arrows pointing down).

to two. These changes were implemented to better resemble the eyes, nose and chin of the agentive stimulus in Experiment 1 so as to provide a more accurate control. There were 192 trials in total, with 96 consisting of symmetrical experimental trials (2 stimulus type × 2 retention interval × 3 gaze direction × 8 repetitions). The direction of motion (left/right) and screen positions of the test stimulus choices were counterbalanced across trials. The remaining trials were distributed equally amongst the other levels of Test stimulus (24 trials each). All other aspects of the stimuli, experimental design, procedure and method of analysis were identical to Experiment 1.

3.2. Results

The mean error rate was 13.2% (SD = 10.1). Participants and trials were excluded based on the same criteria as in Experiment 1, resulting in 7 participants being removed. Of the remaining 26 participants, a total of 2.6% trials were excluded. No further participants were excluded on the basis of information given in the feedback forms.

A repeated measures ANOVA was conducted with stimulus type (horizontal eyes vs. arrows), Retention interval (absent vs. present), Gaze direction (ahead vs. congruent vs. lagging behind) and Test stimulus (−20°/+10° vs. −10°/+10° vs. −10°/+20°) entered as the main effects. As in Experiment 1, the −40°/+10° and −10°/+40° (catch con-

dition) were not included as levels in the test stimulus condition.

Apart from the expected significant main effect of test stimulus ( $F(2,50) = 77.9, p < .001, \eta_p^2 = .76$ ), there were no other significant main effects nor any significant interactions. Crucially, there was no effect of Gaze direction ( $F(2,50) = .813, p = .449, \eta_p^2 = .032$ ) nor of stimulus type ( $F(1,25) = 3.44, p = .075, \eta_p^2 = .121$ ), and there was no interaction between the two ( $F(2,50) = .937, p = .399, \eta_p^2 = .036$ ) (See Table 2 and Fig. 6).

With ‘gaze’ direction and retention interval collapsed, the horizontal ‘eye’ stimulus showed a significant response bias (mean = 67.1%, SD = 47.0) toward overestimation of the final angle ( $t(25) = 3.75, p < .001$ ), as did the arrow stimulus (mean = 58.8%, SD = 49.2) ( $t = 1.94, df = 25, p = .032$ ).

To directly compare these results to those of Experiment 1, the two non-agentive stimulus types of Experiment 2 were collapsed, and entered into a between-subject ANOVA with the agentive stimulus of Experiment 1 as the second level. Retention interval, Test stimulus and Gaze direction were entered as within-subjects factors. There was a significant main effect of Gaze direction ( $F(2,92) = 18.2, p < .001, \eta_p^2 = .28$ ), and crucially this interacted with the between-subjects factor stimulus type ( $F(2,92) = 9.62, p < .001, \eta_p^2 = .17$ ). There were no other significant main effects or interactions, apart from a main effect of Test stimulus ( $F(2,92) = 176.32, p < .001, \eta_p^2 = .79$ ).

Table 2

Mean percentage of ‘after’ choices for each ‘gaze’ direction across each level of test stimulus for the two non-agentive stimuli. SDs of the mean percentages are shown between brackets.

	Horizontal ‘eyes’			Arrows		
	Ahead	Congruent	Lagging	Ahead	Congruent	Lagging
−40°/+10°	98.1 (8.1)	97.1 (6.8)	97.1 (8.1)	97.1 (6.8)	98.0 (8.1)	95.2 (10.0)
−20°/+10°	84.2 (20.6)	77.2 (17.7)	78.4 (25.5)	77.5 (22.9)	75.5 (21.7)	75.5 (25.7)
−10°/+10°	68.5 (26.8)	65.3 (23.7)	67.5 (24.3)	59.9 (23.0)	61.2 (26.0)	55.4 (24.7)
−10°/+20°	36.4 (34.5)	42.0 (29.3)	42.4 (35.2)	41.0 (28.7)	33.7 (28.1)	30.3 (28.2)
−10°/+40°	18.2 (16.5)	10.7 (20.1)	18.8 (21.8)	20.4 (9.2)	4.0 (26.5)	11.7 (19.0)

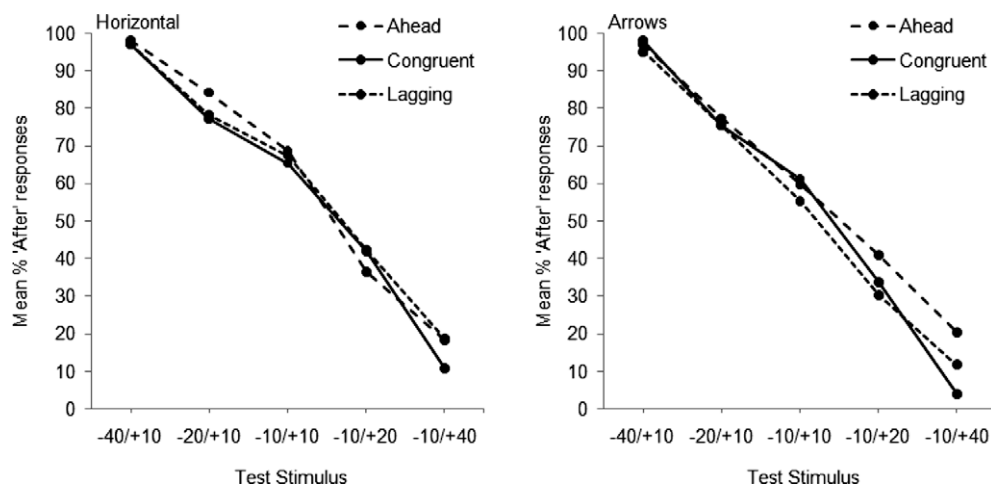


Fig. 6. Mean percentage of ‘after’ choices for each ‘gaze’ direction across each level of test stimulus for two non-agentive stimuli with horizontal ‘eyes’ (left) and arrows (right) (retention interval collapsed).

### 3.3. Discussion

The aim of Experiment 2 was to incorporate two facets of gaze processing into the non-agentive stimulus that the original of Experiment 1 did not possess: horizontal alignment of the eyes and the directional meaning of gaze. The results showed that estimations of object rotation were not influenced by these visual manipulations, neither when oriented to simulate the configuration of the eyes in the agentive stimulus, nor when they held an analogous spatial meaning to that of gaze direction. These results are comparable to those of the non-agentive stimulus in Experiment 1 and therefore further corroborated the main conclusion drawn from Experiment 1, which is that social information conveyed by gaze direction underlies the variations in estimations of head rotation, not their low-level visual appearance nor their spatial meaning. Despite there being no variation in response to the ‘gaze’ manipulations (ahead, lagging, congruent), overestimation of the degree of rotation was evident when they were collapsed, much like the non-agentive stimulus in Experiment 1, suggesting that the motion of the non-agentive stimuli was subject to a conventional RM effect.

## 4. General discussion

This study investigated whether the processing of social cues that are indicative of an agent’s intentions mediated the remembered final position of an action sequence performed by the agent. A rotating head was used to gauge the amount of agentive motion, while varying gaze direction served as a means to control the attributed intentions of the action. Several non-agentive control stimuli that contained visual features equivalent to the eyes of the agentive stimulus were also tested. These controlled for the low-level visual appearance, orientation and spatial meaning of the gaze direction. The stopping point of a rotating head was misjudged if its gaze direction was incongruent with the direction of head motion. That is, the final angle of the head rotation was underestimated when gaze was looking in the opposite direction of the head motion as compared to looking straight ahead or in advance of head rotation. The non-agentive stimuli did not evoke any variation in estimated degree of rotation.

It should be noted that because the immediate perceptual history was provided, inferences about the future trajectory of both the agentive and non-agentive motions were unambiguous. This is relevant, because when presented as a static posture, an incongruent gaze and head orientation would not specify the future direction of motion, as head rotation may have been either towards or away from the target of attention. Head orientation is a significant factor in the processing of gaze direction, and probably helps mediating its social relevance (Hietanen, 1999; Seyama & Nagayama, 2005). The current results unequivocally demonstrate the effect of involuntary intentional coding on the perception and memory of action sequences, and a social cue related anticipation of movement (‘SCRAM’ hereafter).

### 4.1. The relative strengths of the ‘gaze-ahead’ and ‘gaze-lagging’ effects

We hypothesized that when the gaze of an agentive stimulus was directed at the goal of the action (gaze-ahead condition), participants would overestimate the rotational angle of the head, and when gaze was directed opposite to the direction of the goal of the action (gaze-lagging condition) participants would underestimate the angle. It was assumed that that gaze directed at the action goal reflects a larger degree of intentional motivation to reach or achieve the goal than gaze directed opposite to the action direction (Jellema et al., 2000). Both the gaze-ahead and gaze-lagging conditions should therefore have been significantly different from the gaze congruent condition, leading to over and underestimation respectively. However, in the crucial  $-10^{\circ}/+10^{\circ}$  condition, only the results in the gaze-lagging condition supported the hypothesis, whereas the gaze-ahead condition did not differ significantly from gaze congruent. These results suggest that the main effect of SCRAM lies predominantly with the gaze-lagging condition. Apparently participants did not infer any greater intentional information when gaze was directed in advance of head rotation. There are at least three possible reasons for this asymmetry.

Firstly, as a change in gaze direction is a faster and more energy-efficient way to direct attention than a head turn, gaze direction typically ‘leads’ the motion of the head and other body parts (Bertenthal & Von Hofsten, 1998). As a result, gaze-ahead is more perceptually common than gaze-lagging. Possibly, the atypical configuration of gaze and head movement in the gaze-lagging condition made it more conspicuous and was ‘picked up’ and processed more readily. Secondly, even though the deviations of the ahead and lagging gaze directions from head orientation were  $20^{\circ}$  either way, there may have been an asymmetry in the amount of sclera visible, with more sclera visible in the gaze-lagging than in the gaze-ahead condition. Therefore, the visible difference between the lagging and congruent conditions may have been greater than that between the ahead and congruent conditions. The ratio of visible dark pupil with respect to white sclera is a determining factor in ascertaining gaze direction (Symons, Lee, Cedrone, & Nishimura, 2004). Lastly, the difference between gaze-ahead and gaze congruent may have been too subtle to detect using the current method. A more sensitive measure using a set of test stimuli with smaller differences in orientation between the two choices may have elicited an effect. However, these factors do not detract from the robust finding of a consistent difference in the estimation of the degree of head rotation between the gaze-ahead and gaze-lagging conditions.

### 4.2. The role of representational momentum

A secondary aim of this study was to contrast the displacement of agentive motion with the well established effect of representational momentum on the motion of non-agentive stimuli (Freyd & Finke, 1984). In the non-agentive conditions, there was a significant response bias to choosing the ‘after’ choice overall, indicative of an over-

estimation of the degree of rotation. This suggests the control stimulus was subject to representational momentum as a function of the inferred physical forces underpinning its movement, such as its angular velocity (Hubbard, 2005). However, the proportion of 'after' responses elicited by the non-agentive stimuli did not seem to be influenced by the presence or absence of a retention interval. Previous studies have shown that displacement increases as the retention interval increases up to 250 ms, after which no further increases are observed (Finke & Freyd, 1985). No displacement was therefore expected when the retention interval was absent. A likely explanation for this is related to the particular test method used in the current study. Previous studies used one test stimulus, which the participant had to compare with the remembered end-point. The test stimulus in the current study consisted of two objects. This entailed looking at both choices and making a decision, which is a more time consuming process. Hence, a considerable delay between test stimulus onset and pressing the response key was always present (mean = 1415 ms, SD = 665 ms), sufficiently long for displacement to occur, which is consistent with the proposed necessity of higher level off-line mechanisms for the anticipatory memory displacement to manifest itself (Hubbard, 2006).

#### 4.3. Possible neural/cognitive substrates for agentive and non-agentive displacement

Although this study proposes that the anticipation of both agentive and non-agentive motion elicits a distortion in memory for the object's final position, there are reasons to suggest that these effects are underpinned by different neural/cognitive processes. Baron-Cohen (2002, 2006) posits two domains from which an observer is able to attribute causes and constraints underpinning movement in the environment, so as to allow it to become predictable. Systemising relates to the movements of both non-agentive and agentive objects as far as these movements are defined by laws of physics, whilst empathising imbues agentive motion with additional qualities of goal-directedness and intentionality. Hubbard (2006) proposed that the displacement of non-agentive objects is the result of a two factor process. Firstly, the kinematics and dynamics of the object's motion are represented as a functional analogue by means of a second order isomorphism (Shepard & Chipman, 1970). This produces a default displacement based, not upon objective physical principles, but on the observer's subjective interpretation of those principles. Secondly, this displacement can be modulated by the context in which the motion is embedded, such as the type of object and the presence of stimuli, which modulate the displacement. The displacement of agentive motion as a function of social cues observed here concords with this model. The rotation of the head itself is subject to displacement, but when contextualized in terms of goal-directedness by the gaze direction, this displacement is modulated.

The neural mechanism contributing to the SCRAM effect observed could entail the following: through repeated observation of action sequences, the STS associates a particular action with all the (social) cues that accompany and characterise it, such as gaze direction, preceding

movements, spatial location and targets (Baker, Keysers, Jellema, Wicker, & Perrett, 2001; Jellema & Perrett, 2003a; Jellema & Perrett, 2003b; Saxe et al., 2004). On the basis of these statistical inferences it forms expectancies, allowing for the anticipation of the most likely outcome of an action before it is completed (Perrett et al., 2006). The STS thus represents the action in a goal-directed framework. This framework accounts for the mechanistic and probabilistic aspects of the action, but does not account for any motivational inferences, such as desires, fears and beliefs that may motivate the action. However, the STS projects to the inferior parietal lobe which, along with the areas in the ventral premotor cortex, constitute the mirror-neuron system (Rizzolatti & Craighero, 2004). This enables simulation of the others' actions by representing it in the observer's motor system, as if the observer were preparing to perform the action (Gallese, 2006; Iacoboni, 2005). One's own experiences evoked by the sub-threshold embodied simulation inform the observer about the agent's motives. Although mirror neurons have been predominantly observed to process a limited range of biological actions, this does not preclude the presence of mirror neurons coding for additional classes of biological motion such as postures indicative of social attention direction (Keysers & Perrett, 2004). This is a reflexive process and may well underlie the response biases found in the current study. More complex, or unusual, actions may require reflective processes to infer or argue the motivational drives (Lieberman et al., 2002).

#### 4.4. Conclusions

Since the intentions underlying agentive motion are mentalistic in nature, rather than physical, they rely on the observer's ability to represent the mental state of the agent rather than the physical forces acting upon the movement. The current results demonstrate that the perception of agentive motion is subject to displacement as a function of involuntary intentional attributions made by the observer on the basis of bodily cues (SCRAM). This agrees with recent evidence that social cues contribute to the observer's assumptions about how agentive motion will most likely proceed in the immediate future, and that different neural/cognitive mechanisms are responsible for inferences made about agentive and non-agentive motion.

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