The Phenomenology of Eye Movement Intentions and their Disruption in Goal-Directed Actions

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Abstract

The role of intentions in motor planning is heavily weighted in classical psychological theories, but their role in generating eye movements, and our awareness of these oculomotor intentions, has not been investigated explicitly. In this study, the extent to which we monitor oculomotor intentions, i.e. the intentions to shift one's gaze towards a specific location, and whether they can be expressed in conscious experience, is investigated. A forced-choice decision task was developed where a pair of faces moved systematically across a screen. In some trials, the pair of faces moved additionally as soon as the participants attempted to gaze at one of the faces, preventing them from ever viewing it. The results of the experiment suggest that humans in general do not monitor their eye movement intentions in a way that allows for mismatches between planned gaze landing target and resulting gaze landing target to be consciously experienced during decision-making.

Keywords: eye movements; intentions; goal-directed actions; awareness; decision making

Intentions

Psychological models attempting to explain how actions are planned and decided often assume that people generally are aware of what their goals, desires, and attitudes are, and subsequently know their intentions prior to the corresponding planned actions (see e.g. Ajzen, 1991; Dickinson & Balleine, 1994). Furthermore, theories on the sense of agency often position intentions centrally as a type of mental event that are used to directly gauge agency and self-control, where mismatches between one's intention and the outcome of the corresponding action can negatively affect this feeling of agency (Haggard, 2017; Hommel, 2015).

The existence of intentions as clearly distinguishable and introspectively accessible mental events can be questioned though (see also Dennett, 1991). More dynamical approaches to cognition aim to build a complete cognitive architecture without invoking constructs like intentions. Instead, minds might act intelligently through their direct dynamical coupling with the body and environment, as the environment and body directly constrain the possible actions and provide immediate feedback that can be used to tune actions (Van Gelder, 1995; Wojnowicz et al., 2009; Pärnamets et al., 2015). In line with this, much evidence have accumulated against the position that humans have veridical access to their cognitive processes that determine decision-making and action (see e.g. Nisbett & Wilson, 1977; Johansson et al., 2005; Carruthers, 2011).

However, a specific domain which has received very little research in reference to awareness and goal-directed action models are eye movements, and the potential oculomotor intentions guiding them. This is surprising as the connections eye movements have with decision-making are considerable. They have for instance been shown to reflect ongoing thought processes and behavioral goals (Yarbus, 1967), and to be tightly coupled with visual attention (Deubel & Schneider, 1996; Carrasco, 2011); and manipulating people's gaze behavior in real-time can affect preference formations for stimuli and dynamically alter the decision process (Shimojo et al., 2003; Armel et al., 2008; Pärnamets et al., 2015). On top of that, the oculomotor system has been extensively researched, so that much is known about how and which brain areas are involved in controlling eye movements (Girard & Berthoz, 2005; Sparks, 2002). Thus, as eye movements can be measured very precisely and accurately, they serve as good models for studying goal-directed movements (Sparks, 2002).

Following goal-directed action models, one would assume that for every seemingly planned eye movement, there is a corresponding intention that could be brought to awareness should a person want to. But as far as we are aware, no study has investigated whether this actually is the case (closely related studies have for instance mostly investigated low-level factors involved in detecting changes across saccades, e.g. Henderson & Hollingworth, 1999). Typically, our visual experience is acquired in an seamless and effortless fashion, suggesting that even 'planned' eye movements often are processed automatically outside of conscious thought. Yet, common sense suggests that we nevertheless can access and report these plans if called upon, as everyone has had the experience of scanning a scene and purposefully shifting one's gaze towards a particular target within the visual field (for example, when evaluating the flavors on display in an ice cream parlor).

Thus, oculomotor intentions should be particularly salient when a person performs an evaluative task, as they shift their gaze to a specific location or object. Given this, an obvious way to investigate oculumotor awareness would be to manipulate the outcome of someone's eye movements, such that the object she intended to move her gaze towards shifted position during the eye movement. During saccades, visual perception is limited such that it is possible to mask movements of objects (Beeler, 1967; Bridgeman et al., 1975). Therefore, if humans monitor their oculomotor intentions, participants

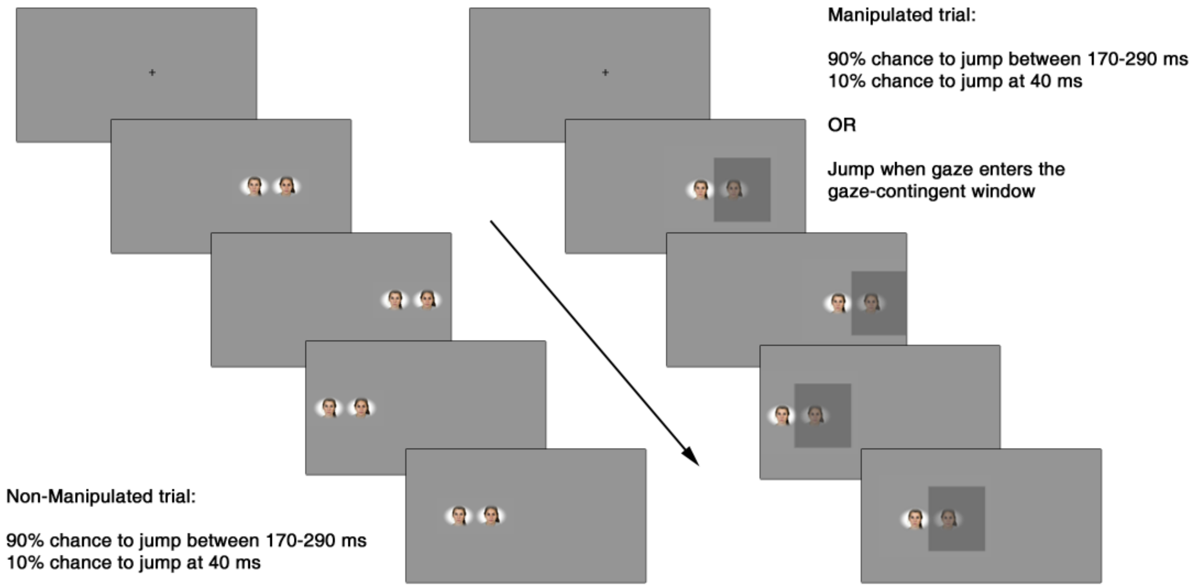

Figure 1: The difference between a manipulated and non-manipulated decision trial. Only manipulated trials were gaze-contingent (the window was not visible). A fixation marker could appear at any of eight horizontally spaced locations, and after a random time between 1 and 2 seconds the faces would appear with the 'back' face (the face at the back of the movement direction) always appearing where the fixation marker was located. The 'front' face appeared either to the left or right of the back face depending on the trial's movement direction. The faces jumped 5 degrees each time (unless they reappeared at the other end of the screen) according to the time pattern, or as soon as a participant's gaze entered the gaze-contingent window.

would become aware of a mismatch between the intention and the outcome when exposed to the manipulation. It would register as a visual error, a curious instance of misseeing.

Here we introduce a novel paradigm to investigate this exact experimental situation. We gave our participants the task of choosing which of two faces moving across a screen they found most attractive. The setup was covertly gaze-contingent in some trials, where our aim was to completely prevent the participants from ever looking at one of the faces in the pair - i.e. as soon as we detected a saccade directed at the target face, both of the images immediately shifted, so that the gaze ended up just where it started. Thus, participants only ever got to fixate on one of the alternatives on those trials (see Figure 1). By making participants' eye movements fail repeatedly in this way, we are able to investigate if oculomotor intentions are consciously monitored. Furthermore, if the effects of disrupting the link between gaze targets and outcomes should go unnoticed, our paradigm can be used to explore how allocation of visual attention might bias the decisions of our participants, and how it influences their recognition and source memory for stimuli and choices.

Method

Participants

31 participants (17 female, 14 male) recruited at Lund University, mostly students (mean age = 26.1 years, *SD* = 7.1), took fully part in the experiment. All participants reported normal or corrected-to-normal vision with contact lenses. The participants received compensation in the form of a gift voucher valid at the movie theater for participating.

Materials and stimuli

The participants had their heads on a chin rest 80 cm in front of a 27-inch LCD monitor (resolution at 1920 x 1080 pixels) with a refresh rate at 120 Hz. The eyes were measured using the Eyelink 1000 (SR Research, Ontario) that recorded monocularly at 1000 Hz, while the experiment was run on Python 2.7.3 using the PsychoPy module (Peirce, 2007). All eye movement data were recorded online after a nine-point calibration (average measured accuracy = 0.47, *SD* = 0.33).

The faces came from the Chicago Face Database (Ma et al., 2015). All faces used were frontal-view Caucasian with neutral expression, rated for a number of attributes including attractiveness, on a 7 point scale. Faces were paired by gender and attractiveness. The faces were divided into three attractiveness groups, the highest 25% belonging to the 'high' attractiveness group, the middle 50% belonged to the 'mid' group, and the lowest 25% belonged to the 'low' group. The images of the faces were resized to 244 (wide) x 172 (high) pixels, with a raised cosine edge to provide softness. The distance between the centers of the images in a pair was approximately 5 visual degrees (230 pixels on the screen at a distance of 80 cm from the eyes, 33 pixels/cm).

Table 1: The set of interview questions, translated into English from Swedish. The primary questions were always asked, while the follow-up questions interjected whenever a participant expressed difficulties in seeing the faces during the experiment.

Primary questions	Follow-up questions
1. How do you feel about the experiment?	1. Why do you think it was like that?
2. Did you think about anything in particular during the experiment?	2. Was it difficult to see the faces in a particular position?
3. How did it feel to make the decisions?	3. Could you fixate both faces?
4. Was there anything in particular that you thought about regarding the decisions?	4. Could you see both faces? If not, what strategy did you use when making the decisions?
5. Did you evolve any strategies for decision-making?	5. Did the decisions feel free or dejected when it was difficult to see?
6. How do you feel about the faces?	
7. Was there anything in particular that you thought about the faces?	
8. Did you notice anything weird about the experiment?	
9. If you had to guess about an undisclosed purpose of the experiment, what would you guess?	

Procedure

Participants were introduced to the experiment, and were told that the purpose of the experiment was to investigate how the movement of alternatives in a decision affected their decision-making. They were told that their pupil sizes would be measured among other measures, but nothing about eye movements. They were also told to make their decisions without feeling pressured for time. The experiment consisted of 60 decision trials and 180 memory trials.

Decision trials and gaze-contingent manipulation In the decision trials, a fixation marker spawned at one of 8 possible positions, and after a random time between 1-2 seconds, the pair of faces appeared, such that the 'back' face (the face at the back of the movement direction) appeared directly where the fixation marker had been, and the 'front' face appeared on the side which would be the direction the faces would jump according to (Figure 1). The pair of faces started their movement pattern immediately after appearing, and the participant had *unlimited* time to make their decision by button-press depending on which face they preferred. After each decision a confidence-scale appeared, where the participant could input their confidence in the previous decision on a continuous scale from 1.00 to 6.00.

The first 5 decision trials were always non-manipulated, while the remaining 55 trials could be either gaze-contingent or not with 50% likelihood for either. The manipulation was programmed to force the participants to view the back face.

In non-manipulated trials the base rate at which the faces jumped was dependent on a few conditions designed to mask the fact that the manipulated trials were gaze-contingent. The time a pair would remain in position was a number of frames of equal probability between 20-35, times the length of time for each frame (at 120 Hz each frame was about 8.3 ms), such that the pair could stay in the same position between 166-292 ms. Additionally, there was a 10% probability that the faces would jump after only 5 frames (42 ms), to produce a more jittery behavior that resembles the gaze-pattern of participants attempting to view a blocked face in purely gaze-contingent conditions. If the faces ever reached the edge of the screen, they would reappear at the other side.

In manipulated trials, the face pair would additionally jump whenever the participant attempted to view the front face. The gaze-contingent jump was governed by a covert gaze-contingent window placed over the front face (see Figure 1). The window had borders distanced 5 visual degrees away from the center of the front face, except in the direction towards the back face, where the window's border extended 3.6 degrees. Whenever the participants' eye gaze was detected within the window a jump was triggered. Otherwise, the movement of the faces continued according to the rules for the non-manipulated trials.

Memory trials Following the decision trials participants completed the memory trials. During each memory trial a face appeared, with instructions asking if they recognized the face. If they answered positively, they were additionally asked whether they think they chose that face in the decision trial it was part of or not. Two-thirds of the faces had been presented previously, while the participants were told that the ratio between old and new faces varied between the participants and would not necessarily be 50/50.

Post-experiment interview After the two phases, the participants were interviewed. There were 9 primary questions asked, but if a participant expressed some suspicion regarding the movement of the faces, or if they expressed that they could not perceive both faces sometimes, a set of follow-up questions intervened (Table 1).

Measures and analysis

To determine whether participants monitored oculomotor intentions consciously to any extent, a set of questions (Table 1) was devised that would probe the participants' subjective experiences, while trying to limit the extent of leading questions that could produce post hoc rationalizations. A set of primary questions was devised to scan for any experiences that could relate to oculomotor intentions. If any response from the participants sufficiently seemed as there could be

Table 2: The frequency of participants belonging to the each category of awareness.

Degree of awareness	Amount
1. No reflections regarding perceiving the faces clearly	3
2. Experienced difficulties perceiving both faces clearly sometimes	18
3. Suspicious that faces were sometimes manipulated to be faint/blurry/unclear	7
4. Experienced feelings that faces sometimes moved according to eye movements	0
5. Suspicious that faces moved according to eye movements	3

some relevant awareness, a set of follow-up questions were interjected, returning back to the primary questions after the follow-up questions were completed. The degree of awareness was divided into 5 categories specifically related to this experiment and are listed in Table 2. The answers the participants provided to the questions asked were then used to categorize them accordingly.

To determine how the manipulation affected decision-making and memory of the faces, generalized linear mixed models (GLMM) were calculated using the **lme4** package in R (Bates et al., 2015). Random effects were modeled as per participant intercepts, and reflecting the fixed effects structure to the closest degree such that convergence was achieved.

Results

Interviews

The division of participants according to the defined degrees of awareness can be seen in Table 2. Very few participants (3) explicitly noticed the manipulation that took place in the experiment, while most participants (18) did not notice the manipulation, but expressed experiencing visual difficulties.

The type of response that was frequent for participants who were categorized in group 2 was for instance that "many of the faces blurred together" or that "they moved so fast that you could not see both clearly." What separated class 2 from class 3 responses were that in the latter case participants explicitly stated that they were suspicious to some degree that the faces were manipulated (although not the movement of the faces specifically). A typical class 3 response was for instance that "I thought about whether the faces were recycled, and whether they were modified," or that "it felt as if it was made up sometimes, as if they were not real people, as if the faces' widths were extended." Importantly, participants belonging to class 3 never expressed that their eye movements affected the movement of the faces, although they could have expressed that where they looked first in a trial might have affected which face got manipulated into looking unreal. No participant was categorized to class 4, as those participants who expressed that their eye movements affected the movement of the faces did so with confidence or highly accurate remarks. Those participants who noticed the manipulation clearly expressed for instance that "I tried to understand how it worked, it felt as if when the eyes moved a lot the pictures moved even more," or that "it felt as if the system did that, that you should look at the picture in the back."

Quantitative data

The time spent per decision trial differed significantly between the trial types, as the participants spent on average more time on the manipulated trials (M = 6.41 s, SD = 5.12 s; for non-manipulated trials: M = 4.69 s, SD = 3.65 s), $t(30)$ = 5.49, $p < .001$. Participants' average confidence responses were also significantly lower for the manipulated trials (M = 3.17, SD = 1.32; for non-manipulated trials: M = 4.01, SD = 1.10), $t(30)$ = -7.36, $p < .001$. While the participants were biased in manipulated trials to only view the back face due to the gaze-contingency, there was also a bias to have spent more time on the the back face for the non-manipulated trials (average time spent on the back face = 1.40 s, SD = 1.20 s; average time spent on the front face = 0.77 s, SD = 0.73 s; average relative time spent on the back face = 65%, SD = 13%). The participants triggered the gaze-contingent manipulation on average 29.3 times per manipulated trial, SD = 24.2.

Decisions The chosen factors for the model on the participants' decision-making were trial type, attractiveness, and their interaction. Non-manipulated, high attractiveness trials were used as baselines. There was a significant effect for manipulated trials as compared to the non-manipulated trials, β = 0.65, SE = 0.22, p = 0.0025, for low attractiveness, β = -0.53, SE = 0.18, p = 0.0036, and the interaction between manipulated trial type and low attractiveness, β = -0.75, SE = 0.28, p = 0.0083. No significant effects were found for the mid attractiveness, β = -0.29, SE = 0.15, p = 0.065, or their interaction, β = -0.23, SE = 0.24, p = 0.33. The model predictions for choosing the back face can be seen in Figure 2. In summary, significant effects on the decisions were found for manipulation, low attractiveness and the interaction between manipulation and low attractiveness.

Memory The participants answered correctly whether the faces they saw were part of the decision trials in 2766 out of 5580 trials (49.6%). Out of the memory trials which progressed into the participant deciding whether she thought she chose the face in the decision it was part of, they were correct in 649 out of 1566 trials (41.4%).

A GLMM was calculated to compute the effects of trial type, attractiveness, the position of the face and the interaction between the position and trial type, on being able to correctly recognize faces in the memory phase. The significant fixed effects were front position as compared to the back position, β = -0.41, SE = 0.11, p <.001; low attractiveness as compared to high attractiveness, β = -0.26, SE = 0.13, p = .034; and low compared to mid attractiveness, β = -0.26, SE = 0.096, p = .0067. The fixed effect manipulated as compared to non-manipulated trial type showed no significance accord-

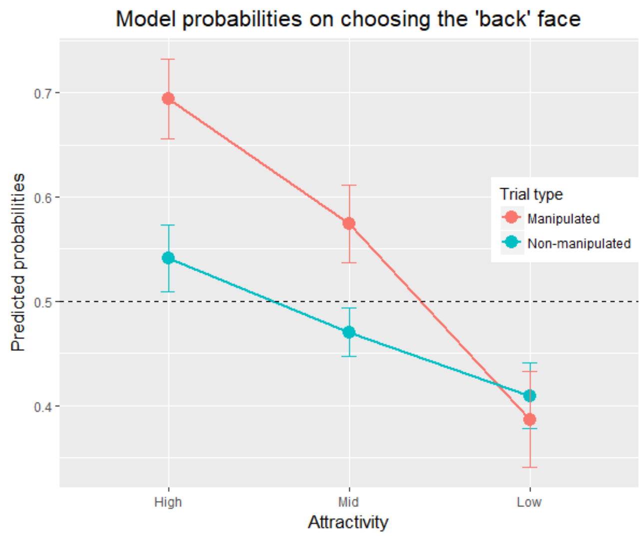

Figure 2: The predicted probabilities and their standard errors on choosing the back face, which in manipulated trials was the only possible face to directly fixate on. The values include the effect of the interaction between attractivity and trial type.

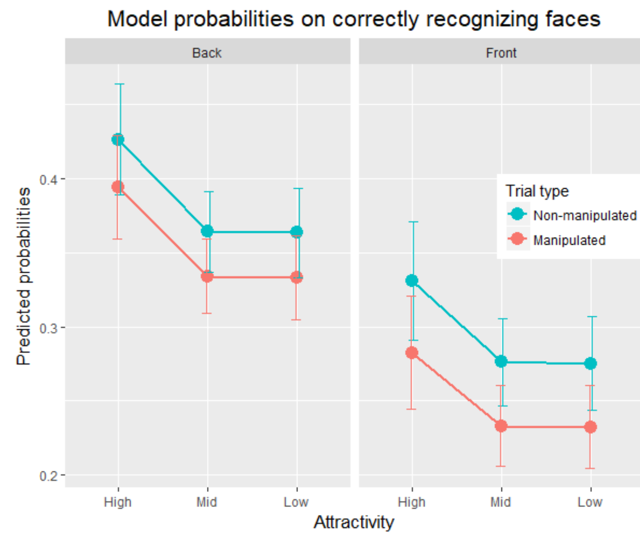

Figure 3: The predicted probabilities and their standard errors on responding correctly to the source memory task. The predictors are face position (either back or front in the direction movement), trial type, and attractiveness, with an interaction between trial type and face position. The model excluded recognition trials with new faces.

ing to this model, β = -0.13, SE = 0.10, p = .19, and the interaction between manipulated trial type and front position was not significant either, β = -0.094, SE = 0.15, p = .54. In summary, recognition memory was superior for the back face compared to front face, and high attractiveness faces compared to low and middle.

Trial type, attractiveness, position and interaction between position and trial type were the factors used to model the task of answering the source memory question correctly. Significant fixed effects were found for manipulated trials as compared to non-manipulated trials, β = 0.47, SE = 0.22, p = .033, and for the interaction between manipulated trials and the front position, β = -0.88, SE = 0.39, p = 0.025. Non-significant effects were found for low attractiveness as compared to high, β = -0.20, SE = 0.17, p = 0.23, low compared to mid attractiveness, β = -0.16, SE = 0.14, p = 0.27, and front position as compared to the back position, β = 0.31, SE = 0.21, p = 0.15. The model probabilities for correctly remembering whether preferred the faces they recognized can be seen in Figure 3. In summary, significant effects were found for the manipulation and the interaction between the manipulation and the front position.

Discussion

In this paper we introduced a novel gaze-contingent manipulation technique to introduce mismatches between oculomotor intentions and their outcomes. We found that participants generally do not monitor their oculomotor intentions to the degree that would be posited by goal-directed action models. Additionally, we found that the effect of forcing participants' gaze towards one option in this specific way biased their decisions and later memories.

Degree of awareness

The results from the interview provided with the surprising data that most of the participants did not become aware of the manipulation in the experiment. It was surprising because of the high number of manipulations each participant was exposed to, which was on average 29.3 times per manipulated trial (although not all of these are the result of a direct saccade from the back to the front face). That means that every participant was exposed to on average almost a thousand manipulations, even if each manipulation was subtle. But one thing that made it even more surprising that so few participants expressed awareness of their eye movements failing to reach one of the faces on some trials, was that each participant had full control over their exposure to the gaze-contingency, as they were the one's who decided when the trial ended, by making their choice. By choosing themselves when to end the decision, without any experiment-based time pressure, they made the indication that they were satisfied with making a decision, at least to some degree, even if they felt that it was difficult to see one of the alternatives. And the results on the memory tasks supports the fact that the manipulation was successful in blocking the seeing of the front face in manipulated trials, as there was a significant reduction in recognition memory for blocked faces in the manipulation trials. The same holds for the data on the participants' source memory, as they were better at correctly remembering if they chose a back face if it took part in a manipulated trial compared to a non-manipulated trials, which likely was due to the increased exposure to back faces on average on manipulated trials compared to non-manipulated. Participants were also worse at correctly remembering if they chose a front face that was part of a manipulated trial compared to a non-manipulated trial, which reasonably results from the manipulation blocking them from viewing that face. This leads us to believe that we are not monitoring our oculomotor intentions in a direct conscious way, at least when engaged in decision-making.

On the other hand, it is highly possible that the manipulation affected participants consciously in other ways, such as their sense of agency, and confidence in their ability to make accurate decisions in the visually demanding task. This would require further investigations, which would provide with information that could improve our models on goal-directed actions.

Decision-making

Given that most participants were naive to the manipulation, the effect the manipulation had on their decision-making is of general interest. On manipulated trials, if the face was part of the high attractivity group, the participants had about a 15% increased likelihood (from about 55 to 70%) of choosing the back face (to which their gaze was forced). That effect is not small, and supports previous research on the effect the dynamics of eye movements have in decision-making (Shimojo et al., 2003; Pärnamets et al., 2015). But what is also interesting is how the direction of the effect switches for low attractivity faces. Here, the participants were more biased in their choices towards the front face instead, with the likelihood of choosing the back face dropping down to about 40%. The striking thing here is that in manipulated trials the participants could not see the front face, yet were more likely to choose that face which they did not see. This supports the view that more exposure to unappealing stimuli decreases ones preference for it (Armel et al., 2008). Again, follow-up work is necessary to replicate and fully understand these findings.

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