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Looking ahead: Attending to anticipatory locations increases perception of control

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ABSTRACT

When people manipulate a moving object, such as writing with a pen or driving a car, they experience their actions as intimately related to the object's motion, that is they perceive control. Here, we tested the hypothesis that observers would feel more control over a moving object if an unrelated task drew attention to a location to which the object subsequently moved. Participants steered an object within a narrow path and discriminated the color of a flash that appeared briefly close to the object. Across two experiments, participants provided higher ratings of perceived control when an object moved over a flash's location than when an object moved away from a flash's location. This result suggests that we use the location of spatial attention to determine the perception of control. If an object goes where we are attending, we feel like we made it go there.

1. Introduction

As video game enthusiasts can attest, the sensation of controlling an object as it moves on a display can be quite compelling. An avatar that runs and jumps in response to our button presses can vividly feel under our control. This is true even though we only experience the consequences of our actions in one sensory domain—vision. If an avatar jumps upwards when we depress a button, the visual information from the display is sufficient for us to feel like we caused the avatar to move. What aspects of our visual experience influence our perceived control over an object? What role do well-known visual processes such as attention play in determining if an action was a product of our own conscious will?

Previous research investigating the perception of control has described several key components. One approach to understanding control stems from feed-forward models of motor control which posit that we run simulations of our movements and also monitor the feedback from these movements (Jordan & Rumelhart, 1992; Miall & Wolpert, 1996). We perceive control when there is minimal discrepancy between predicted and actual sensory-motor feedback (Farrer & Frith, 2002; Frith, Blakemore, & Wolpert, 2000). Evidence from video game-like tasks in which participants attempt to control an object moving on a computer display are consistent with feed-forward models; players require onscreen feedback within 0.2 s of performing an action to feel in control (Bickford, 1997). Participants report increasing perception of control as discrepancies between motor input and visual feedback decrease (Dewey, Seiffert, & Carr, 2010; Metcalfe & Greene, 2007) and action control relies primarily on visual information (Sutter & Müsseler, 2010). Our perception of control is also influenced by the perceived success of our actions. Judgments of control correlate with performance (Metcalfe & Greene, 2007). In addition, people perceive

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more control over an object when an autopilot function actually takes control away from an observer but moves the object closer to the goal (Dewey et al., 2010). Partial automation of motor task tools in video games also facilitates perception of control (Mallon, 2008). When our expectations about an action are met—through a match between projected and actual low-level sensory feedback or via fulfillment of a higher-level goal—we are more likely to perceive ourselves as in control of that action.

Another prominent approach to understanding perception of control places less emphasis on feedback and action goals and more emphasis on inferential processes. The theory of apparent mental causation posits that we feel as if we have consciously willed an action when we believe that our own thought caused the action (Wegner, 2002; Wegner & Wheatley, 1999). According to this theory, three factors influence the extent to which we attribute an action to a particular thought: priority, consistency, and exclusivity. The perception of control is strongest when our thoughts directly precede our actions (priority), are compatible with these actions (consistency), and are the only apparent cause of the actions (exclusivity). After completing an action, the actor creates the conscious experience of control by inferring agency from how thoughts relate to actions.

Experimental investigations of the perception of control have produced evidence consistent with the theory of apparent mental causation. Priming the effects of an action can increase an observer's perception of having controlled that action. In one such study, Wegner and Wheatley (1999) asked participants to share control of a cursor with a confederate. The pair moved the cursor over a display filled with small objects while listening to a random list of object names. On some trials, the participant was allowed to stop the cursor when she wished, but on other trials, the confederate stopped the cursor on a particular object. The experiment manipulated the time between when the subject heard the name of a potential target object and when the confederate stopped on the target. Participants were more likely to mistakenly report that these stops were under their own control if they heard the name of the object just before the action occurred. Hearing the name of an object—and presumably thinking about the cursor moving to this object—made participants feel like they had willfully produced the action of stopping on the object. In a similar vein, Wegner, Sparrow, and Winerman (2004) found that an auditory preview of another actor's hand motions led observers to report higher feelings of vicarious agency over these movements. Encouraging people to think about an action right before it happened made them more likely to perceive they themselves controlled the action. Additional research demonstrated that even subliminal priming of action effects enhances feelings of action authorship, outside of intentional or goal-directed thinking (Aarts, Custers, & Wegner, 2005). More recent evidence suggests that both the inferential processes of apparent mental causation and the predictive components of feed-forward models contribute to the perception of control (Haggard & Cole, 2007; Moore & Haggard, 2008; Moore, Lagnado, Deal, & Haggard, 2009).

While these investigations provide explanations for the influence of low-level perceptual feedback as well as high-level inferences on perceived control, the middle ground remains relatively unexplored. Cognitive functions determine how perceptual information is combined with previous knowledge, biases and goals to bring about conscious experience. How do cognitive functions play a role in determining our conscious experience of agency? How are language, memory, and attention involved in the perception of control? Here, we begin to examine these issues by focusing on one of these cognitive systems.

We investigated the influence of visual attention on the perception of control. Visual attention is the modulator that regulates visual information to fit current goals and intentions (for a review see Chun, Golomb, & Turk-Browne, 2011). To effectively control objects, people direct visual attention to the locations at which their actions are aimed (Mennie, Hayhoe, & Sullivan, 2007; Pelz & Canosa, 2001) and to the locations where they expect to find visual feedback about these actions (Wulf, Höss, & Prinz, 1998; see Wulf, Shea, and Lewthwaite (2010), for a review). We hypothesize that spatial attention plays an important role in the perception of control. In the case of controlling a moving object—such as moving an avatar in a video game—we propose that an observer first determines a short-term goal (e.g., making the avatar take a step to the left). Next, the observer directs visual attention to the location of this goal and executes a motor response (e.g., tapping a button). The observer then evaluates the visual feedback at the location of attention, checking to see if her avatar now occupies that location. The observer feels in control of the moving object because it went to the location where she had directed attention.

This hypothesis suggests that observers will experience increased perception of control when expected visual changes occur where they have directed attention. Manipulating the location of spatial attention may therefore have significant effects on the perception of control. Perhaps we can modulate the extent to which an observer feels in control of a moving object simply by directing her to attend to one location vs. another. In other words, it may be possible to produce a sensation of control—making an observer feel as if she directed a moving object to go to a particular location—simply by asking her to attend to a location the object will subsequently occupy.

Across two experiments, we asked participants to engage in a simple visuo-motor task while we manipulated their visual attention to see if the location of attention influences perception of control. Participants attempted to steer a moving object and maintain a specific course in the face of interfering input (see Fig. 1). At the same time, they attended to the sudden appearance of a flash that drew their attention to different locations relative to the object they were controlling. We tested the hypothesis that when participants' visual attention was drawn to a location the moving object subsequently occupied, they would report higher perception of control than when their attention was drawn to another equidistant location.

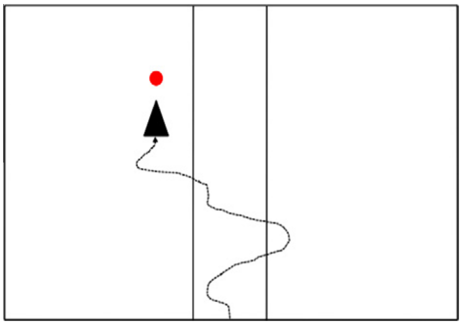

Fig. 1. Display for a Front Flash trial in Experiment 1. Participants attempted to keep the triangular boat inside the central lane as invisible waves knocked it to the left and right. During the trial, a dot would briefly flash somewhere near the boat. At the end of each trial, participants provided a rating of their perceived control for that trial and reported the color of the flash. The dotted line represents the boat's path and was not actually visible on the display. (Note that in the actual experiment, the boat and lines were white and the display background was black.)

2. Experiment 1

In Experiment 1, we examined how manipulations of visual attention and object movement influenced perceived ratings of control. Participants attempted to steer an object as it moved up a computer display and judged their level of control of the object. We added a secondary task asking participants to simultaneously monitor for the appearance of a briefly presented flash that required a color discrimination judgment to direct visual attention to specific locations. The flash could appear either in front of the moving target (Front Flash) or behind it (Back Flash). Eye movements were not controlled, so both overt and covert attention could have been influenced. On some trials, participants maintained continuous control over the object's movements (Autopilot Off condition), while on other trials control of the object's movements was briefly automated to ensure the object moved over a specific location (Autopilot On condition). At the end of each trial, participants reported their perceived level of control over the object.

2.1. Method

2.1.1. Participants

Sixteen volunteers from Vanderbilt University participated for monetary compensation.

2.1.2. Stimuli and apparatus

The display was shown on a color monitor set at a resolution of 1024×768 pixels running at a refresh rate of 89 Hz. The participants viewed a white triangle that was approximately 0.8° of visual angle, moving across a display of two white vertical lines (24° long and separated by 5°) on a black background (Fig. 1). A red[1] or blue circular flash that was 0.5° in diameter appeared briefly next to the triangle. Participants sat approximately 24 in. from the monitor.

2.1.3. Procedure and design

During a trial, participants attempted to steer the triangle, called "the boat", to keep it centered in the display between the two vertical lines. The boat moved steadily upwards and was knocked to the left and right by an invisible force called "the waves". Each trial began with a static display showing the vertical lines for 670 ms, then showing the boat stationary at the bottom of the display for 340 ms. The boat then moved for 4.2 s, going from the bottom to the top of the screen at a constant rate of approximately 5°/s. The strength of the waves varied across trials, moving the boat horizontally at a rate of approximately 5°/s (Weak Waves), 20°/s (Medium Waves), or 40°/s (Strong Waves). Wave direction varied randomly (left, right, or none) every 150 ms. Participants pressed keys to counteract the effects of these waves. Each key press caused the boat to move left or right at approximately 5°/s for 170 ms, with multiple key presses having cumulative effects. Steering performance was recorded as the total number of frames during which the boat fell outside of the central vertical lane.

At a random time between 560 and 3370 ms into the trial, a colored flash appeared on the screen for 200 ms. This flash appeared either approximately 1° in front of the boat or 1° behind the boat. On half the trials, after the appearance of the flash, the boat continued to move horizontally based on wave strength and key press inputs (Autopilot Off condition). On the other trials, the boat moved straight up for 400 ms following the flash's appearance, then continued to move horizontally based on wave strength and key press inputs (Autopilot On condition). Therefore, in the Autopilot On condition, the boat automatically moved directly over the location of a Front Flash and directly away from the location of a Back Flash.

After each trial ended, participants rated their perceived level of control over the boat on an ordinal 9-point scale with 1 being the lowest control rating and 9 being the highest. Participants also indicated whether the flash for that trial was red or

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

blue. Desaturated colors were used to make the color discrimination task difficult. Half of participants provided the control rating first and half of participants provided the color response first.

Participants performed a practice block of eight trials with Weak Waves for which data were not analyzed, followed by four blocks of 72 trials each with wave strength (Weak, Medium, Strong), flash location (Front Flash, Back Flash), flash color (red, blue) and autopilot (Autopilot Off, Autopilot On) fully counterbalanced.

2.2. Results and discussion

Trials in which participants incorrectly identified the flash color were excluded from analysis (13.7% of trials). Participants made significantly more flash color identification errors when the flash appeared behind the boat than when it appeared in front of the boat (62% vs. 38% of color errors; $t(15) = 4.93$, $p < .001$). This result suggests that participants may have been biased to pay more attention to the space in front of the boat than the space behind it, perhaps directing attentional resources near the goal (i.e., the top of the display).

Initial analyses demonstrated that our manipulation of wave strength had a substantial impact upon both ratings of perceived control ($F(2,30) = 81.37$, $p < .001$, MSE = 2.02) and steering performance ($F(2,30) = 1230.86$, $p < .001$, MSE = 639.40). Consistent with theories suggesting that feed-forward predictive motor processes influence the perception of control (e.g., Blakemore, Wolpert, & Frith, 2002), stronger waves impaired steering performance and lowered ratings of perceived control. However, this manipulation did not interact significantly with either the autopilot or flash location manipulations (all interaction p-values > .4).

To test our hypothesis that participants will perceive greater control over an object when they attend to a location over which the object moves, we evaluated the influence of flash location and autopilot on perceived control ratings. Fig. 2 shows participants' average ratings of perceived control across conditions. Participants reported higher perceived control when the flash appeared in front of the boat than when it appeared behind the boat (main effect of flash location $F(1,15) = 5.94$, $p < .03$, MSE = 0.02), but only when the autopilot steered the boat directly over the flash location (interaction $F(1,15) = 11.56$, $p < .01$, MSE = 0.01), supporting our hypothesis. Interestingly, the autopilot function had no independent influence on ratings of perceived control (main effect of autopilot $F(1,15 = 0.30$, ns). That is, although we actually took control of the boat away from participants for 400 ms in the Autopilot On condition, this manipulation did not make participants perceive themselves as less in control, presumably because the autopilot steered the boat straight toward the goal (Dewey et al., 2010).

Did participants perceive greater control over the boat when the autopilot steered the boat over a flash location because their actual steering performance was best in this condition? Fig. 3 shows participants' average steering performance across conditions. Although the boat moved outside of the central lane for fewer frames under the Autopilot On condition than under the Autopilot Off condition ($F(1,15) = 5.89$, $p < .03$, MSE = 24.10)—an unsurprising result given that participants had to contend with an extra 400 ms of wave inputs in the Autopilot Off condition that were not present in the Autopilot On condition—the location of the flash did not influence steering performance ($F(1,15 = 0.04$, ns), nor did it interact with the autopilot manipulation ($F(1,15) = 0.22$, ns). Participants did not actually demonstrate more control over the boat when it moved over a flash location, suggesting that while our attention manipulation influenced perceived control ratings, it did not affect performance.

3. Experiment 2

Although the results of Experiment 1 provide an initial demonstration that observers perceive more control over an object when it moves over an attended location than when it moves away from an attended location, in this experiment front flashes were always closer to the goal location than back flashes. Participants were more accurate in identifying front flashes than back flashes, so it is possible that an attentional bias towards the top of the display created the conditions necessary for

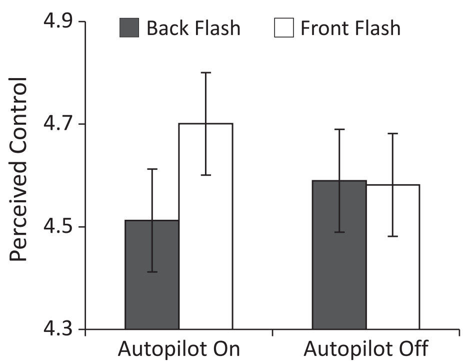

Fig. 2. Average ratings of perceived control (taken on a scale from 1 to 9) in Experiment 1.

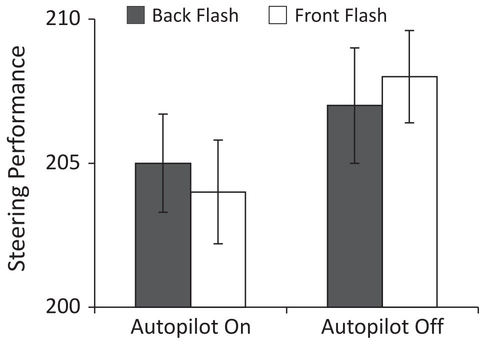

Fig. 3. Average steering performance (number of frames in which the boat was outside of the central lane) in Experiment 1.

participants to perceive greater control when an object moved over an attended location. Will observers also perceive more control over objects that move over attended locations than objects that move away from attended locations when this attentional manipulation is disentangled from distance to the goal?

Participants in Experiment 2 once again attempted to steer a boat up a computer display while also monitoring for the color of a brief flash. However, unlike Experiment 1, flashes in Experiment 2 never appeared directly ahead of or directly behind the boat, but instead were randomly presented either ahead and to the left, or ahead and to the right of the object. An autopilot function steered the boat for a short time after the flash appeared, either towards or away from the flash location. While flashes always appeared somewhere ahead of the boat, the manipulation of whether the boat did or did not pass over the flash location was independent of the flash's proximity to the goal. If, as we propose, visual attention specifically contributes to the perception of control, then participants in Experiment 2 should rate their control as higher when the boat moves toward the flash than when it moves away from the flash, regardless of where the flash appears.

3.1. Method

3.1.1. Participants

Sixteen undergraduate volunteers from North Dakota State University participated for course credit.

3.1.2. Stimuli, apparatus, procedure, and design

Participants in Experiment 2 performed the same boat steering and flash color identification task as participants in Experiment 1. However, in Experiment 2, flashes appeared at a 45° angle from the boat, approximately 1° above and to the left or 1° above and to the right of the boat. On every trial, after the flash appeared, the boat moved either up and to the left or up and to the right of the boat for 400 ms, regardless of participants' manual input. Flash location (left vs. right) and autopilot direction (left vs. right) were fully counterbalanced such that the boat moved toward the flash location for half of the trials and an equal distance away from the flash location for the other half of trials. After performing a practice block of eight trials, participants completed five blocks of 48 trials each.

3.2. Results and discussion

Participants incorrectly identified the flash color on 16.8% of trials. Flash color errors occurred about as often when the flash appeared ahead and to the left of the boat as when it appeared ahead and to the right of the boat (51% vs. 49% of color errors; $t(15) = 0.57$, $p > .5$), suggesting that participants were not biased to attend more to flashes at one location than another. Data for these error trials were excluded from our analysis of control ratings and steering performance.

Our primary question of interest for Experiment 2 was whether participants would perceive higher control over the boat when it was briefly steered toward the location of a flash than when it was steered away from the flash. Consistent with our hypothesis that visual attention influences perception of control independently of relationships between attended and goal locations, participants reported higher perceived control when the boat moved toward the flash ($m = 5.39$) than when the boat moved away from the flash ($m = 5.23$) ($t(15) = 2.99$, $p < .01$). This difference in perceived control ratings did not seem to be driven by a difference in actual boat steering performance across conditions, as the boat moved outside of the central lane for almost the same number of frames when it was steered toward the flash ($m = 208$; 2.3 s) as when it was steered away from the flash ($m = 210$; 2.4 s) (t(15 = 1.44, $p > .1$). Experiment 2 therefore replicates the overall findings of Experiment 1, showing that participants perceive more control over objects that go to locations where they are attending, and extends this finding to situations in which manipulations of attention are not confounded with the goal of the object-moving task.

4. General discussion

Across two experiments, we have demonstrated that spatial attention plays a role in the perception of control. Participants in our study attempted to keep a boat centered in the face of invisible waves as it traveled up a computer display. Consistent with models of agency tied to predictive motor control processes (Blakemore et al., 2002), we found that when participants had to fight against stronger waves, they were both less able to keep the boat in the central path and also perceived less control over the boat. Our results also support the priority hypothesis of the theory of apparent mental causation (Wegner, 2002; Wegner & Wheatley, 1999), with the assumption that priority is modulated by attention. Participants felt most in control of the boat when an autopilot function steered it directly over a location where we had drawn their attention with a colored flash, both when the flash was on the path to the goal (Experiment 1) and when there was no relationship between the flash location and the goal (Experiment 2). Here, we evaluate the role of visual attention in object control by arguing that people use visual attention actively to anticipate visual feedback.

Our observations are consistent with the theory that inferential processes drive perception of control. Across experiments, when the boat moved over a location where we had drawn participants' attention, it made them feel as if they meant for it to go there. Framed in terms of the priority hypothesis, we encouraged people to think of a specific location, so when the boat went to that location, they were more likely to feel responsible for this outcome. Even though we directed participants' attention with an independent color judgment task that had no influence on control performance, matching the location of spatial attention with the controlled object was sufficient to increase perceived control. Moreover, our data point to the power of visual attention to produce illusory feelings of control. When the autopilot steered the boat toward the flash, the object was completely out of participants' control for almost half a second, yet these were still the conditions where participants reported feeling most in control. This suggests that visual attention may serve as a conduit for expected visual feedback to support the perception of control. People may judge the effectiveness of their actions in a spatial task by first directing spatial attention to a location consistent with the goal of their immediate action and then evaluating subsequent visual information on the basis of the location of visual attention. As an example, tennis players may evaluate their swing by attending to the location on the ground where they were attempting to place the ball and evaluating the visual perception of the ball relative to the location of visual attention.

Control of motor action is well described by mechanisms that regulate the relationship between input and output. The brain uses internal models to select motor actions and to predict perceptual outcomes (see Miall (2003) for a review). Forward models are generated with motor commands to estimate future states and modulate sensory inputs. As an example, the corollary discharge that accompanies an eye movement helps preserve the continuity of visual perception over a saccade (for a review see Wurtz, 2008; Hall & Colby, 2011). Discrepancies between forward models and perceptual feedback provide assessment of the control of action. Prefrontal and parietal cortex are responsible for this modeling and evaluation process (for a review see Creem-Regehr, 2009; Stanley & Miall, 2009), including the execution of intended actions and the sense of agency (Chambon et al., 2012; Farrer & Frith, 2002; Haggard, 2005; Iacoboni, 2006; Tanji, Shima, & Mushiake, 2007). Research suggests that visual attention plays an important role in organizing and priming information related to anticipated actions (Baldauf & Deubel, 2008, 2009, 2010), with even some of the more ballistic aspects of action planning showing limitations similar to attentional limitations (Enns & Liu, 2009). Here we extend this work to suggest that even when attention is directed by an incidental concurrent task, it can impact the evaluation of actions.

The idea that visual attention can be an agent for other cognitive mechanisms has also arisen in other domains. It has been proposed that people seem to continuously attend to locations in order to maintain the relevance of those locations (e.g., Awh & Jonides, 2001; Awh, Jonides, & Reuter-Lorenz, 1998; Smyth & Scholey, 1994). In a similar vein, visual attention has also been proposed as an agent for inter-saccadic remapping of visual information (Cavanagh, Hunt, Afraz, & Rolfs, 2010; Hunt & Cavanagh, 2011; Rolfs, Jonikaitis, Deubel, & Cavanagh, 2011). Work in the saccadic remapping and visual working memory domains suggests that the visual system can elegantly employ attention as an active agent, reducing the need for extensive internal representations or calculations. We propose that visual attention also serves as an efficient way for people to evaluate the extent of their control through visual feedback.

Visual attention also can be a powerful tool in guiding higher-level aspects of conscious experience, such as thought. Previous research has shown that problem solving processes are influenced by shifts in visual attention. Participants were more likely to solve a difficult spatial reasoning problem when their attention was guided along a path that was consistent with the problem's solution (Thomas & Lleras, 2007, 2009). In other words, by making participants attend to a relevant pattern of locations, the experimenters were able to guide participants' thoughts to a target solution. Likewise, in the current study, we have shown that by guiding visual attention to a relevant location along an object's path of movement, we can also influence participants' thoughts, making them feel more in control of this object.

In conclusion, we have found a new factor that influences the perceived control over an object. When participants were directed to attend to a location where an object subsequently went, they perceived more control over this object. This result exposes the potential of investigating a new middle ground in perceived control, showing that in addition to low-level sensory and high-level metacognitive influences, perception of control is also mediated by visual attention. Future research is necessary to determine whether this mediation was a result of a shift precipitated by movement of the eyes or a shift executed via covert mechanisms. However, regardless of whether participants in our study made a saccade or covertly shifted their attention to flash locations, it is clear that when an object moved over these locations, it influenced their perception of control. These results may also provide at least one explanation for why video games can sometimes feel frustratingly beyond our control; in situations where our attention is engaged at locations far from an avatar, we may feel much less in control of that avatar.

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