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Outside influence: The sense of agency takes into account what is in our surroundings

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ABSTRACT

We are quite capable of distinguishing those outcomes we cause from those we do not. This ability to sense self-agency is thought to be produced by a comparison between a predictive representation of an outcome and the actual outcome that occurs. It is unclear, though, specifically what types of information can be entered into agency computations. Here, we demonstrate that information from non-target stimuli (stimuli that are not directly acted upon) incidentally present in our surroundings can influence predictions of outcomes, consequently modulating the sense of agency over clearly-defined target outcomes (those that occur to acted-upon stimuli). This provides the first evidence that our sense of agency is contextualized with respect to what is in our immediate visual environment. Furthermore, our data suggest that agency computations, instead of just a single comparison, may involve comparisons performed in stages, with different stages involving different types/classes of information. A model of such multi-stage comparisons is described.

1. Introduction

In general, we are able to effectively distinguish the outcomes we cause from those we do not. This ability to sense our agency in actions and outcomes is a central one because it grounds our "sense of self" (Knoblich & Flach, 2003) and enables us to distinguish ourselves from others and the operations of the natural world. Additionally, in our social interactions, we generally assign credit and apportion blame on the assumption that individuals can sense their own responsibility in given outcomes (Bandura, 2001; Haggard & Tsakiris, 2009).

A sense of agency (SoA) is thought to be produced by a comparison process in which a mental representation of a predicted outcome is compared to the actual outcome that occurs (Frith, Blakemore, & Wolpert, 2000; Moore & Haggard, 2008; Sato & Yasuda, 2005; Wegner & Wheatley, 1999). A match between the predictive representation and the actual outcome produces a strong sense of agency. On the other hand, a mismatch between the two produces feelings of *non-agency* (or lack of agency). For instance, a ball that travels in a direction and with a speed consistent with the force with which it is thrown will likely produce a strong sense of agency in the thrower. A ball that travels backwards towards the thrower (a mismatch with what would be predicted regarding direction of movement), however, will more than likely produce a strong sense of non-agency. Supporting this, experimental manipulations that affect the relationship between predicted and actual outcomes have been found to reliably influence SoA, producing *agency distortions*. On one hand, manipulations that act to minimize matching between predicted and actual outcomes result in a reduced sense of agency (Sato, 2009; Sato & Yasuda, 2005; Wenke, Fleming, & Haggard, 2010). For example, in one study, the application of mild spatial noise to an outcome such that spatial matches between predictions and actual outcomes were slightly reduced produced lower levels of SoA (Farrer & Frith, 2002). (It should be noted that outright spatial incongruence or mismatches (e.g., a stimulus moving left when the prediction is that it will go right) between predictions and actual outcomes will produce a clear sense of non-agency.) On the other, situations in which an actual outcome appears to match a predicted one result in an elevated sense of agency, and this is so even when an individual may not have had any real control over the outcome in question (Hon & Poh, 2016; Pronin, Wegner, McCarthy, & Rodriguez, 2006; Wegner, Sparrow, & Winerman, 2004; Wegner & Wheatley, 1999). In a seminal study (Pronin et al., 2006), participants who undertook a faux magical ritual aimed at harming another individual reported greater levels of SoA when the targeted person subsequently reported feeling ill. In reality, the ritual did not have any actual influence and the targeted individual was, in fact, a confederate. In this case, "vicarious agency" was produced because the outcome matched the participants' predictions regarding the outcome of the ritual.

While the comparison model described above has been very successful in explaining its production, it is nonetheless the case that SoA is generally studied under highly constrained circumstances. In some

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typical experiments, participants are introduced to a single stimulus that they try to control via some behavior (e.g., a button press or joystick movement), with the actual stimulus outcome being consistent with their actions or not (Dewey, Seiffert, & Carr, 2010; Ebert & Wegner, 2010; Hon, Poh, & Soon, 2013). In others, participants perform some motor action and are presented with somatosensory outcomes that are linked with the action or not, judging agency over the production of these outcomes (Chambon, Moore, & Haggard, 2015; Sidarus, Chambon, & Haggard, 2013; Wenke et al., 2010). In these paradigms, it is common for target stimuli/outcomes to be presented in isolation, being the only information presented at a given time. One concern is that this may give the impression that SoA is driven solely by signals from target stimuli/outcomes and nothing else. In everyday life, however, the stimulus one acts upon may not be the sole stimulus present in the environment. An open question, then, pertains to whether or not non-target stimuli (stimuli that are not acted upon) incidentally present in the environment can influence SoA over outcomes relating to an acted-upon target stimulus. To date, the literature has been silent on this issue.

In this study, we investigated the possibility that information regarding extraneous, non-target stimuli can be factored into agency computations; in particular, the predictive representations of outcomes. Consider, for example, a standard table setting in which a dinner plate is flanked by a knife and fork. If one were to push the plate, one would clearly predict that it should move forward in a manner consistent with the push applied. If it does this when pushed, one should feel a strong sense of agency. In this case, though, the prediction involves only information from the target stimulus (i.e., the plate). However, it could also be predicted that, in addition to moving in a direction consistent with the push, the plate should end up further away from the knife and fork. Notice that, in this latter scenario, information about the knife and fork is extraneous to the acted-upon stimulus (i.e., the plate) but is built into the prediction nonetheless. In the current study, we investigated this issue - whether information about extraneous, non-target stimuli can be built into predictive representations.

Here, participants viewed displays that comprised a central rectangle (target) flanked on the left and right by two other rectangles (non-targets). The target rectangle was always a different colour from the non-target rectangles (Fig. 1). Participants made self-decided and self-initiated presses of the up- or down-arrows on a standard computer keyboard when the display was presented. Following a button press, the target rectangle would move in a direction consistent with that indicated by the button press or not. The task was to assess agency over the movement of the target rectangle. Consistent with the literature, we would expect high agency ratings when the target's movement matched the direction indicated by the button press and low ratings when these were incongruent. Of greater relevance here, at the same time as the target moved, the adjacent non-targets could do one of three things: They could move in the same direction as the target rectangle, move in the opposite direction or remain stationary. If, as in the plate and cutlery example above, predictions include the (spatial) relationship between target and simultaneously-present non-target stimuli, then, in the current experiment, the prediction associated with a given button-press would be that the target rectangle should (a) move in a direction consistent with that indicated by the button press and (b) end up further away from the non-targets than before the action was performed. Accordingly, the best matches should occur when the target moves in a direction consistent with the button press and when it ends up clearly separated from the non-targets. Thus, in this study, when there is congruence between button press and target movement, one would expect the greatest SoA to be reported when the target and non-targets move in opposite directions. This would produce the greatest final distance between the two, offering the clearest evidence of a match with the prediction. Similarly, the lowest agency ratings should be observed when target and non-targets move in the same direction, as the final spatial separation between the two would be smallest in this case. It is also worth pointing out that this paradigm allowed us to probe the matching of predictions while keeping target signals constant. Notice that target signals, in any given target condition, were the same regardless of what the distractors did.

It is worth pointing out that what is being studied here is different from earlier studies that have reported that stimuli like primes can sometimes affect agency ratings over a target action/outcome (Aarts, Custers, & Marien, 2009; Aarts, Custers, & Wegner, 2005; Chambon & Haggard, 2012; Linser & Goschke, 2007; Wenke et al., 2010). While it is possible to characterize such primes as non-target stimuli, their purpose was to affect the fluency with which agentic actions could be performed (Chambon & Haggard, 2012; Sidarus et al., 2013). Thus, while they were non-targets, they were not extraneous to the task. The non-targets in the current study are different in that they neither hinder nor aid action choice or the actual movement of the target. Thus, the non-target stimuli of this study were designed to function more genuinely as extraneous environmental stimuli.

2. Experiment 1

2.1. Methods

2.1.1. Participants

29 undergraduate students from the National University of Singapore participated in this experiment.[1] All participants had normal or corrected-to-normal vision.

2.1.2. Procedure

In the experiment proper, participants completed a single block comprising 240 trials of a simple agency judgement task. On each trial, three coloured rectangles were presented side-by-side in the centre of a white screen (Fig. 1). The middle rectangle (designated the target) was of one colour, while the two flanking rectangles (non-targets) were of another. The two colours used for the rectangles were red and blue, and the assignment of the colours to target or non-targets was counterbalanced across participants.

In response to the presentation of the rectangles, participants made self-initiated and self-decided up- or down-arrow key presses. A hundred milliseconds (100 ms) after the key-press, the target rectangle moved in a direction that was either congruent (e.g., moving up after an up-arrow key-press) or incongruent (e.g., moving down after an up-arrow key-press) with the direction indicated by the key-press. These were designated *Target Congruent* and *Target Incongruent* trials respectively. The distance travelled by the target rectangle was 5.14° of visual angle, regardless of direction. The movement of the target lasted 120 ms. Target Congruent and Target Incongruent trials each accounted for 50% of all trials.

When the target moved, one of three things could happen with respect to the flanking non-targets. These could move in the same direction as the target (e.g., upwards when the target moved up), in an opposite direction to the target (e.g., downward when the target moved up), or they could remain in their original position. These are termed *Non-target Same*, *Non-target Different* and *Non-target Neutral* trials respectively. Non-target Neutral trials, in which the non-targets remained stationary accounted for 50% of all trials, with the remaining 50% of the trials being split equally between Non-target Same and Different conditions. Non-target movements began at the same time and were of the same speed as the target. However, they only moved one-third the distance travelled by the target (~1.74° of visual angle). Correspondingly, their movement lasted a shorter time (~ 40 ms) than that of the target. The difference in amount of movement was, like the use of different colours, meant to promote disambiguation between targets and non-targets.

[1] Sample size was determined on the basis of other studies form our lab using the same base paradigm (e.g., Hon et al., 2013).