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Eyes that bind us: Gaze leading induces an implicit sense of agency

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ABSTRACT

Humans feel a sense of agency over the effects their motor system causes. This is the case for manual actions such as pushing buttons, kicking footballs, and all acts that affect the physical environment. We ask whether initiating joint attention – causing another person to follow our eye movement – can elicit an implicit sense of agency over this congruent gaze response. Eye movements themselves cannot directly affect the physical environment, but joint attention is an example of how eye movements can indirectly cause social outcomes. Here we show that leading the gaze of an on-screen face induces an underestimation of the temporal gap between action and consequence (Experiments 1 and 2). This underestimation effect, named 'temporal binding,' is thought to be a measure of an implicit sense of agency. Experiment 3 asked whether merely making an eye movement in a non-agentic, non-social context might also affect temporal estimation, and no reliable effects were detected, implying that inconsequential oculomotor acts do not reliably affect temporal estimations under these conditions. Together, these findings suggest that an implicit sense of agency is generated when initiating joint attention interactions. This is important for understanding how humans can efficiently detect and understand the social consequences of their actions.

1. Introduction

The effects our motor system have on the environment need to be accurately detected. Action monitoring in humans gives rise to a *sense of agency* whereby we become conscious of our own actions (Gallagher, 2000). Such actions might be grasping objects or pushing buttons. However, some of the most important actions we execute do not directly affect the non-social, physical world, but do affect the *social* world. That is, some actions lead to changes in other people's actions (e.g. Caspar, Christensen, Cleeremans, & Haggard, 2016). One such ubiquitous social action is that when we look somewhere, other humans may spontaneously reorient their own gaze in the same direction, thus establishing joint attention (Frischen, Bayliss, & Tipper, 2007). Joint attention is an everyday but important example that shows that, although eye movements cannot directly affect inanimate objects (aside from modern emerging gaze-controlled technologies, Slobodenyuk, 2016), changes in our gaze direction can influence other *people*. Moreover, saccades are the most common action we perform; we foveate a new area of the visual field 3–5 times each second (Schiller, 1998). However, there is little evidence that saccades evoke a sense of agency in a similar way to manual actions. We, therefore, tested whether an implicit sense of oculomotor agency over a conspecific's gaze shift response emerges in joint attention.

Because eye movements are a special form of action, they may not necessarily engage the same mechanisms underpinning agency as those engaged by other effectors. Nevertheless, there is a clear advantage in having robust agency detection systems for social outcomes elicited by our own actions, so a common mechanism that generalises between all effectors and outcome types could also be posited. Efficiently detecting the social effects we have caused may be critical to understanding others' actions and support mental state ascription (Happé, Cook, & Bird, 2016). Thus, the importance of understanding the role for agency in social action is critical for the understanding of social cognition.

There is one recent paper that suggests that people can learn to understand the contingencies between their saccades and a bouncing ball stimulus on a screen (Grgič, Crespi, & de'Sperati, 2016), which is an initial piece of evidence that the effects of saccades can be explicitly self-attributed. However, explicitly measuring sense of agency does not provide a full picture and can be problematic. This is because explicit measures are somewhat limited as self-reported feelings of control over an action depend on the actor's own ability for introspection (Barlas & Obhi, 2013; David, Newen, & Vogeley, 2008; Sebanz & Lackner, 2007). Moreover, as Gallagher (2012) points out, self-agency is not normally something of which we are typically aware. Explicit measures are further criticised for their susceptibility to response bias and impression management (Obhi, 2012). Because of this, an alternative is to measure sense of agency implicitly with a measure that does not ask the participant to introspect about their explicit experience of control. Inferring

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sense of agency from implicit measures of correlated, potentially underlying mechanisms, has been a revealing approach (Barlas & Obhi, 2013). This can be achieved by exploiting an effect known as temporal binding (Haggard, Clark, & Kalogeras, 2002), whereby perception of the temporal distance between act and outcome is compressed for self-generated acts, and relatively accurate when judging the gap between two non-self-related stimuli (Moore & Obhi, 2012, for a review). This is why the temporal binding effect is theorised to measure an implicit sense of agency (see Haggard, 2017, for review).

Here, we adopt a twofold approach of measuring the sense of agency: temporal binding (which we offer as an implicit measure of agency) and self-reported ratings of felt control (an explicit measure of agency). We considered this necessary because explicit measures and binding effects do not always correlate, suggesting they may not reflect the exact same processes (e.g. Dewey & Knoblich, 2014, but see Ebert & Wegner, 2010, where changes in temporal binding were found to be related to explicit self-reports of agency). This possible dissociation between explicit and implicit agency are incorporated into an optimal cue integration account where implicit agency operates at a sensorimotor level, whilst explicit agency emerges following higher level processing (see Synofzik, Vosgerau, & Voss, 2013).

Relatedly, sense of agency may arise both from predictive model-based mechanisms and postdictive mechanisms (Blakemore, Wolpert, & Frith, 2002; Haggard, 2017; Synofzik et al., 2013). According to the predictive model, the sense of agency is produced when there is a match between the predicted and the actual sensory outcome from an action (Blakemore et al., 2002). The retrospective or postdictive model, however, conceptualises a comparison between the action's idea and action's effect and a sense of agency arises if they are similar (Chambon & Haggard, 2013). Moore, Wegner, and Haggard (2009) argued that different, and varied, agency cues are integrated to result in a sense of agency (e.g. consequences of actions and sensorimotor prediction). Moore, Middleton, Haggard, and Fletcher (2012) tested this by exploring whether explicit and implicit agency were modulated differently by sequential patterns of action and outcome. Their results supported a model in which explicit and implicit agency can be thought of as dissociable, but, they argued, the two are not completely independent systems. This is consistent with Synofzik et al.'s (2013) optimal integration cue account in which explicit and implicit agency can both be included. Given this reviewed evidence, we aimed to measure the temporal binding effect associated with an implicit sense of agency and collect self-report explicit ratings of agency as a manipulation check.

The temporal binding phenomenon has been associated with implicit sense of agency over physical actions that cause auditory (e.g. Barlas & Obhi, 2014), and visual outcomes (Cravo, Claessens, & Baldo, 2011). Investigations of interpersonal agency have been more limited, though agency is recognised as a critical aspect of joint action (Sebanz, Bekkering, & Knoblich, 2006). Some studies have demonstrated a sense of agency over others' actions during joint tasks (Obhi & Hall, 2011; Pfister, Obhi, Rieger, & Wenke, 2014), and by illusory agent misidentification (e.g. Wegner, Sparrow, & Winerman, 2004). Interpersonal dynamics can modulate agency (e.g. under social coercion, Caspar et al., 2016). Social outcomes of physical acts have been studied by Yoshie and Haggard (2013), who showed that the valence of human vocalisations that served as a consequence of their participants' actions modulated temporal binding (but see Moreton, Callan, & Hughes, 2017). These studies offer some evidence that a *social outcome* from a button press can elicit binding. In one version of this paradigm, participants are asked to replicate the time interval they have just experienced (e.g. Humphreys & Buehner, 2010). We apply this notion of social sense of agency, measured using a time interval reproduction paradigm, to a crucial component of social cognition – joint attention – a key way in which humans communicate.

The above-reviewed binding evidence suggests that the socio-affective consequences of actions are coded in a generally similar way to non-social outcomes. Previous studies have shown saccade control can be guided by action-outcome effects, albeit in a non-social context (e.g Huestegge & Kreutzfeldt, 2012; Riechelmann, Pieczykolan, Horstmann, Herwig, & Huestegge, 2017). Relatedly, one eye-tracking study demonstrated that action-effect associations are made by the oculomotor system within a social context (Herwig & Hortsmann, 2011). Participants learned that their saccades triggered changes to onscreen facial expressions and adjusted their saccade accordingly. When they anticipated their saccade would trigger a smiling face, saccades landed near the mouth region and when they anticipated triggering a frown, saccades landed near the eyebrow region. This revealing finding illustrates how oculomotor actions can be influenced by perceived outcomes within a social context.

The actions studied thus far in the temporal binding literature are mostly restricted to button presses (see Moore & Obhi, 2012, for a review). In joint attention, the initiating act is an eye movement, whereby the gaze leader looks at an object, and a follower orients their attention to the same object (Frischen et al., 2007). Recent work has shown that people more efficiently detect instances when their gaze has been followed (Edwards, Stephenson, Dalmaso, & Bayliss, 2015), and that leading others' gaze has consequences for subsequent interactions with those individuals (Bayliss et al., 2013; Dalmaso, Edwards, & Bayliss, 2016). Having one's eyes followed may necessarily involve the generation of a sense of agency over another's congruent gaze response. Indeed, people do explicitly express a feeling of control (Pfeiffer et al., 2012) and naturalness (Bayliss et al., 2013) in such scenarios. Establishing with temporal binding that similar processes underpin implicit agency in social gaze orienting as with physical acts, would be an important advance in our understanding of how social attention operates. Specifically, such a finding could help to explain why noticing that someone else has followed your gaze to establish joint attention is such a powerful experience, despite it being a common occurrence (e.g. Bayliss et al., 2013; Edwards et al., 2015). That is, rather than merely detecting that one's gaze has been followed, we interpret the social response as a causal outcome of our initial action.

Alternatively, it may not be this straightforward. There are also reasons to think that social agency might operate very differently to non-social agency. We have an enormous amount of experience of our physical manipulations of objects in the environment producing temporally contiguous outcomes. For example, when we kick a ball, it immediately moves. Therefore, the temporal window within which we become aware that our actions have produced an outcome are easily predictable. However, when we produce an action in order to elicit an outcome in another person, the temporal contiguity of the outcome has much more variance, making it harder to predict (Kunde, Weller, & Pfister, 2017). For example, a person may not immediately respond to our request to pass us an object nor may they immediately respond to our gaze signals, if their attention was elsewhere. The variance inherent in social interactions is one reason why implicit agency might work differently in social compared with non-social contexts. On the one hand, the variance might mean that temporal binding effects associated with implicit sense of agency might not emerge at all because social agency detection relies on higher-level mechanisms such as Theory of Mind (Premack & Woodruff, 1978) to make sense of social cause-and-effect. On the other hand, the instability of social interactions might actually elicit very reliable effects because of the critical importance of social agency detection, which could be underpinned by a system flexible enough to tolerate the inherent variance. Therefore, whether saccades that cause a social outcome could elicit temporal binding associated with implicit agency is an interesting open question for work both on social cognition and action monitoring.

In two experiments, we tested the hypothesis that gaze leading elicits temporal binding, which is offered as a measure of an implicit sense of agency (see Haggard, 2017, for a review). Participants' time interval reproductions between an object's appearance and an onscreen face looking at that object were compared between two tasks: an active