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# Self-reference in action: Arm-movement responses are enhanced in perceptual matching☆

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ABSTRACT

Considerable evidence now shows that making a reference to the self in a task modulates attention, perception, memory, and decision-making. Furthermore, the self-reference effect (SRE) cannot be reduced to domain-general factors (e.g., reward value) and is supported by distinct neural circuitry. However, it remains unknown whether self-associations modulate response execution as well. This was tested in the present study. Participants carried out a perceptual-matching task, and movement time (MT) was measured separately from reaction-time (RT; drawing on methodology from the literature on intelligence). A response box recorded 'home'-button-releases (measuring RT from stimulus onset); and a target-key positioned 14 cm from the response box recorded MT (from 'home'-button-release to target-key depression). MTs of responses to self- as compared with other-person-associated stimuli were faster (with a higher proportion correct for self-related responses). We present a novel demonstration that the SRE can modulate the execution of rapid-aiming arm-movement responses. Implications of the findings are discussed, along with suggestions to guide and inspire future work in investigating *how* the SRE influences action.

## 1. Introduction

An extensive literature now demonstrates the self-reference effect (SRE): that is, performance is faster and/or more accurate across attentional, perceptual, decision-making, and memory-based tasks when stimuli are associated with the 'self' as opposed to (e.g.) another person or a neutral item (Conway & Pleydell-Pearce, 2000; Humphreys & Sui, 2015; Schäfer, Wentura, & Frings, 2017; Sui & Humphreys, 2015; Symons & Johnson, 1997; for a review see Cunningham & Turk, 2017). Studies using a socio-associative perceptual-matching paradigm (Sui, He, & Humphreys, 2012), have further shown that the SRE is independent of stimulus familiarity, cannot be reduced to domain-general factors (e.g., inherent reward value, positive emotional valence, or semantic elaboration; see Humphreys & Sui, 2015; Sui & Humphreys, 2015), utilises domain-specific information (Sun, Fuentes, Humphreys, & Sui, 2016), and is supported by distinct neural circuitry (Sui, Rotshtein, & Humphreys, 2013).

To date, studies using Sui and colleagues' matching paradigm to investigate the SRE have typically focused on early and perceptual processing. The SRE has been shown, for example, to modulate access to visual awareness (Macrae, Visokomogilski, Golubickis, Cunningham, & Sahraie, 2017), and attention (Sui, Liu, Wang, & Han, 2009). The SRE has also been demonstrated when the paradigm has been transferred to audition and touch (Schäfer, Wesslein, Spence, Wentura, & Frings, 2016). Few studies, however, have examined the influence of the SRE on later processing (cf. Constable, Welsh, Huffman, & Pratt, 2018; Siebold, Weaver, Donk, & van Zoest, 2015; Stein, Siebold, & van Zoest, 2016), and none have directly examined effects on response execution.

Frings and Wentura (2014) examined the effects of self-prioritization and an action variable in Sui et al.'s (2012) paradigm. The authors instructed participants to associate labels with arm movements, and then (cued by a directional cursor) to execute these movements in the matching task. A label was then presented after the arm-action had terminated, and participants had to judge using button-presses whether the movement and label matched. The authors documented a reaction-time (RT) advantage in matching the 'self' label to its corresponding arm movement. As Schäfer, Wentura, and Frings (2015) note, these findings revealed a performance advantage in matching the 'self' label with an 'action representation'. Response execution itself was not directly measured.

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Recently, Macrae and colleagues (2017) reported a study designed to assess the influence of the SRE on access to visual awareness. Using a hierarchical-diffusion-model analysis, and in contrast to Frings and Wentura (2014), the authors decomposed task performance on Sui et al.'s (2012) paradigm. It was found that the SRE influenced both decisional as well as non-decisional processes. However, since non-decisional processes can include one or both of stimulus encoding and response execution, it remains unclear whether response execution can be modulated by self-associations.

Currently, there is no theoretical model available which explicitly links mechanisms of self-reference with response execution processes. Mechanistic understanding of the SRE is still in its infancy, and focus has so far been on processes in perception and attention (see e.g., Humphreys & Sui, 2016). In contrast, however, the mechanisms underlying response priming (RP) – a paradigm that has been used extensively to explore visuomotor processing [or early and perceptual processing effects on response generation] – have been well-documented (Schmidt, Haberkamp, & Schmidt, 2011).

'Rapid chase theory' (Schmidt, Niehaus, & Nagel, 2006) posits two components of visuomotor processing: an initial bottom-up, feed-forward activation of the visual system in stimulus processing which leads to rapid and direct motor activation, and which is independent of visual awareness. This is contrasted with a slower, top-down-controlled, 'recurrent processing' component, arising in later processing, that feeds back to influence re-entrant activity, as well as developing visual awareness (Schmidt & Seydell, 2008). The SRE has been proposed to modulate both bottom-up processes and top-down attentional control mechanisms, and also to operate outside of visual awareness (Macrae et al., 2017; although cf. Constable et al., 2018; Stein et al., 2016).

Researchers in RP have been able to dissociate effects of the two modes of visual processing on response execution, by varying task parameters in terms of the SOA of the 'prime' (a stimulus presented below the threshold of awareness) and target stimuli (available to conscious perception), and their response compatibility and incompatibility mappings (see e.g., Schmidt et al., 2011). In particular, a variant of RP (which investigates the time-course of primed pointing movements) has enabled researchers to dissociate early pre-conscious versus late processing effects on visual motor control: The initial "feed-forward sweep" triggered by the prime stimulus (Schmidt et al., 2006) has been shown to drive early parts of the movement (or, under certain conditions, even the whole response – e.g. generating overt errors on stimulus-response incompatibility trials).[1] The slower (top-down) target-stimulus processing can then take over movement control mid-flight (with this time-point tightly-linked to the SOA), and further influence response execution 'online' as it unfolds (Schmidt et al., 2011; Schmidt & Seydell, 2008). The SRE, then, could operate within either or both of these modes of visual processing and exert an influence response execution.

As well as potentially interacting with established modes of processing, an SRE in action may involve processes that are qualitatively distinct. The SRE has been shown to be supported by distinct neural circuitry (Sui, Rotshtein, & Humphreys, 2013). In particular, imaging work (Sui, Rotshtein, & Humphreys, 2013) has revealed that the SRE arises from a functional coupling of the ventral medial prefrontal cortex (vmPFC) – an area associated with self-representation – and the left posterior superior temporal sulcus (lpSTS; the ventral attentional network linked to social attention). In contrast, other-person-related responses on the same task activated the dorsal frontoparietal attentional control network. In a recently proposed processing network – the Self-Attention Network [SAN] model (Humphreys & Sui, 2016) – (which has yet to be integrated into the processing frameworks so far understood in RP), self-associated stimuli are held to rapidly activate a self-representation located in the vmPFC, which then primes responses in the pSTS and enhances bottom-up driven (orienting) processing of self-related stimuli. Top-down (fronto-parietal) attentional control (associated with the intra parietal sulcus; IPS) can enhance self-related responses by engaging with prior expectancies for self-stimuli, but also inhibit bottom-up-driven self-related responding for other-person-related responses (Humphreys & Sui, 2016). The involvement of distinct self-related circuitry, then, could support visuomotor processing effects that are qualitatively distinct from those previously found in the case of RP. There may also be overlap, however, through the interaction with top-down and bottom-up mechanisms.

In terms of the slower, top-down, later (recurrent) and online processing outlined in RP, there is some suggestion that the SRE could influence response execution via this route. In the SRE literature, it has been shown that not only can the SRE be enhanced by increasing expectancies for self-stimuli, but that these expectancies dominate performance over those for other-person-related stimuli (Sui, Sun, Peng, & Humphreys, 2014). RP theory holds that when stimuli match expectations regarding stimuli and their assigned responses, the corresponding motor response is triggered directly (Kiesel, Kunde, & Hoffman, 2007). In terms of online control (Khan et al., 2006), it has been found in ownership paradigms, for example, that perceived social context can modulate the kinematics of unspeeded (non-rapid) reach-and-grasp actions. Constable, Kritikos, Lipp, and Bayliss (2014) found that participants' reaches to their own rather than the experimenter's mug were straighter; in contrast, reaches to the experimenter's mug exhibited a curved trajectory. However, these studies were designed to investigate a different construct ('ownership' – see Constable et al., 2018) and type of action (unspeeded reach-and-grasp) from the current study (and evidence is equivocal, for example, that a perceptual SRE remains intact in these paradigms; Constable et al., 2018).

In terms of bottom-up processing, RP research indicates that visual attention can intensify the first waves of bottom-up visuomotor processing (Schmidt & Seydell, 2008). Heightened stimulus energy (e.g., in stimulus contrast) has been shown to produce increased feed-forward activity which builds activation more rapidly in cortical motor areas linked to movement execution (and shortens response times; Schmidt et al., 2006). Similarly, higher-intensity stimuli increase activation to the response stage, which increases response force (Ulrich, Rinkenauer, & Miller, 1998). If the vmPFC 'primes' attentional responses in the pSTS to self-stimuli (Humphreys & Sui, 2016), the SRE could potentially influence response execution via e.g. a saliency-akin-driven mechanism. Indeed, effects of self-reference have been compared to those of highly perceptually-salient stimuli. Responses are faster and more accurate, reduced stimulus contrast does not affect the SRE (Sui et al., 2012), and the bias is arguably somewhat automatic (Alexopoulos, Muller, Ric, & Marendaz, 2012; Humphreys & Sui, 2015; Sui et al., 2014; although cf. Ocampo & Kahan, 2016). Furthermore, in a level-priming paradigm, both perceptual saliency and self-reference were shown to modulate target selection in hierarchical stimuli (Liu & Sui, 2016) and both modulate attentional suppression mechanisms that recruited the IPS (Sui, Liu, Mevorach, & Humphreys, 2013).

The SRE is not simply a general saliency-driven effect, however. For example, the effects of the semantic distinctiveness of stimuli can be dissociated from the SRE (Schäfer et al., 2017), and when stimuli are both socially- and highly-perceptually-salient, response accuracy is increased relative to the effects of simply perceptually-salient stimuli (Liu & Sui, 2016). Furthermore, perceptual and 'social salience' (a term coined by Sui, Liu, et al. (2013) to describe effects of self-reference on early processing) also activate distinct neural areas (Sui, Liu, et al., 2013). Effects of perceptual saliency are thought to originate from early visual areas. In contrast, those of 'social saliency' are thought to be generated in the vmPFC (Liu & Sui, 2016). Therefore, as noted, the SRE may be able to influence one or both of the modes of visuomotor processing (identified in RP). However, the recruitment of a dedicated 'self-

[1] Prime information typically drives the errors in inconsistent conditions (where the prime stimulus is mapped to a different response than the target stimulus) and can lead to a full-blown response error (Schmidt et al., 2011).