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The effects of freedom of choice in action selection on perceived mental effort and the sense of agency

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ABSTRACT

Previous research showed that increasing the number of action alternatives enhances the sense of agency (SoA). Here, we investigated whether choice space could affect subjective judgments of mental effort experienced during action selection and examined the link between subjective effort and the SoA. Participants performed freely selected (among two, three, or four options) and instructed actions that produced pleasant or unpleasant tones. We obtained action-effect interval estimates to quantify intentional binding – the perceived interval compression between actions and outcomes and feeling of control (FoC) ratings. Additionally, participants reported the degree of mental effort they experienced during action selection. We found that both binding and FoC were systematically enhanced with increasing choice-level. Outcome valence did not influence binding, while FoC was stronger for pleasant than unpleasant outcomes. Finally, freely chosen actions were associated with low subjective effort and slow responses (i.e., higher reaction times), and instructed actions were associated with high effort and fast responses. Although the conditions that yielded the greatest and least subjective effort also yielded the greatest and least binding and FoC, there was no significant correlation between subjective effort and SoA measures. Overall, our results raise interesting questions about how agency may be influenced by response selection demands (i.e., indexed by speed of responding) and subjective mental effort. Our work also highlights the importance of understanding how subjective mental effort and response speed are related to popular notions of fluency in response selection.

1. Introduction

Sense of agency (SoA) refers to the sense that one is in control of their actions and the outcomes of these actions (Gallagher, 2000; Haggard & Chambon, 2012; Haggard & Tsakiris, 2009). Research investigating the underlying mechanisms of the SoA has suggested that both prospective and retrospective processes contribute to the SoA at varying strength and degree depending on the context (Desantis, Weiss, Schütz-Bosbach, & Waszak, 2012; Moore & Fletcher, 2012; Moore, Wegner, & Haggard, 2009; Synofzik, Vosgerau, & Lindner, 2009; Synofzik, Vosgerau, & Voss, 2013). Prospective processes are mainly concerned with pre-movement anticipations calculated by internal forward models (Blakemore, Wolpert, & Frith, 2002; Frith, 2005; Frith, Blakemore, & Wolpert, 2000; Wolpert, 1997; Wolpert, Ghahramani, & Jordan, 1995) and processes involved in action selection such as selection fluency (Chambon & Haggard, 2012; Chambon, Wenke, Fleming, Prinz, & Haggard, 2013; Haggard & Chambon, 2012; Wenke, Fleming, & Haggard, 2010). Retrospective processes, on the other hand, are related to higher level judgments and inferences (e.g., Wegner, 2004; Wegner & Sparrow, 2004; Wegner & Wheatley, 1999). The contribution of these processes has been examined by considering several factors that surround human actions.

One important factor that has been suggested to significantly influence one's SoA is the freedom of choice associated with making a particular action (for an exception see Sidarus & Haggard, 2016). Accordingly, it has been shown that "feeling of control" (FoC) over action-outcomes was stronger when participants could freely choose one of two actions in a high proportion of trials compared to when they were mostly to perform an instructed action (Wenke et al., 2010). In addition to the subjective judgments of agency, intentional binding was also found to be influenced by choice. Intentional binding refers to the perceived temporal attraction between voluntary actions and their outcomes (Haggard, Clark, & Kalogeras, 2002), and has been used as an implicit measure of the SoA (Engbert & Wohlschläger, 2007; Engbert,

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Wohlschläger, & Haggard, 2008; Haggard et al., 2002; Moore & Obhi, 2012). A previous study examined the effect of varying the number of action alternatives (one, three, or seven) on intentional binding and found that binding was strongest when participants could freely chose an action among seven alternatives compared to performing a fixed (instructed) action (Barlas & Obhi, 2013). This finding was supported by a recent study (Barlas, Hockley, & Obhi, *under review*) that investigated the influence of outcome valence in free (selected among four options) and instructed actions on both intentional binding and FoC judgments, and found enhanced intentional binding and FoC when actions were freely selected compared to when instructed.

An important question regarding the effect of choice on the SoA is concerned with the mechanisms that mediate this effect. One potential explanation could be that the involvement of internal processing is greater when the brain selects an action among several alternatives compared to when action selection is carried out externally. This "active mode" (Caspar, Christensen, Cleeremans, & Haggard, 2016) of the brain in action selection could explain why SoA is stronger in free in contrast to instructed actions. Several brain imaging studies have supported this view. It was found, for instance, that the contrast between free choice and instructed actions is associated with increased BOLD activity in dorsolateral prefrontal cortex (DLPFC), inferior parietal lobe (IPL), rostral cingulate zone (RCZ), and supplementary motor area (SMA) (Cunnington, Windischberger, Deecke, & Moser, 2002; Filevich et al., 2013; Lau, Rogers, Haggard, & Passingham, 2004; Lau, Rogers, & Passingham, 2006; Waszak et al., 2005). Greater activation in SMA in free choice of actions is particularly interesting as this area has been shown to be linked to the intentional binding effect (Cavazzana, Penolazzi, Begliomini, & Bisiacchi, 2015; Kühn, Brass, & Haggard, 2012; Moore, Ruge, Wenke, Rothwell, & Haggard, 2010). Additionally, a recent tDCS (transcranial direct current stimulation) study showed that anodal stimulation of DLPFC enhanced temporal binding of actions and outcomes when the actions were freely chosen, suggesting a critical role of this area in endogenous processing of actions (Khalighinejad, Di Costa, & Haggard, 2016).

Although neuroimaging studies provide some interpretation of the effect of free choice on the SoA, other factors such as higher level beliefs and subjective experience of effort during action selection could also contribute to this effect. For instance, free action selection could bolster one's sense of autonomy (Schwartz, 2012), which could lead to the belief that they have stronger FoC over their actions. Another possibility is that the effect of choice on the SoA could be mediated by the *perceived* mental effort in action selection. In this vein, effort in action selection can be considered from at least two perspectives. First, previous research has suggested that fluent action selection can enhance the SoA (Chambon et al., 2013; Chambon & Haggard, 2012; Haggard & Chambon, 2012; Sidarus & Haggard, 2016; Wenke et al., 2010). The term selection fluency in the majority of these studies, however, was determined by the conflict or incongruency between primed and performed actions and was suggested to influence the SoA prospectively. Additionally, other studies on the influence of task-irrelevant mental effort on the SoA (e.g. by manipulating the working memory load) showed that increased mental effort weakened both binding (Howard, Edwards, & Bayliss, 2016) and FoC (Hon, Poh, & Soon, 2013).

Another aspect of effort in action selection, as we propose here, is the subjective experience of mental effort during action selection. The important question is then whether free actions that involve, as noted above, greater internal processing are perceived as more effortful compared to instructed actions, and whether perceived mental effort could be related to the effect of free vs instructed choice on the SoA. The main goal of the current study was to investigate this question. Accordingly, choice of actions (i.e., key presses) was parametrically varied from one (instructed) option to two, three, and four options. Each key press produced an auditory outcome after one of three intervals (100 ms, 300 ms, and 500 ms) and between subjects, we obtained both interval estimations of key press-outcome delays (Caspar, Cleeremans, & Haggard, 2015; Ebert & Wegner, 2010; Engbert et al., 2008; Moore et al., 2009; Moore & Haggard, 2010; Obhi, Swiderski, & Farquhar, 2013) and FoC ratings over the outcomes. Additionally, in a post-experiment task, participants rated how much mental effort they felt when choosing which key to press in each choice-level condition.

Our second goal was to further investigate the effect of outcome valence on the SoA, particularly on intentional binding. Although there is solid evidence that FoC is stronger over positive compared to negative outcomes (Barlas & Obhi, 2014; Barlas et al., *under review*), the influence of outcome valence on binding proved to be more complex. For instance, it was found that binding was attenuated with negative compared to positive or neutral outcomes (Yoshie & Haggard, 2013), enhanced with pleasant compared to unpleasant outcomes (Barlas & Obhi, 2014), and enhanced with outcomes that are linked to positive monetary gains (Takahata et al., 2012). More recent studies, however, found either no effect of outcome valence on binding (Moreton, Callan, & Hughes, 2017, Barlas et al., *under review*) or showed that this effect could be dependent on the predictability of valence and occurrence of action-outcomes (Christensen, Yoshie, Di Costa, & Haggard, 2016). More clearly, Christensen et al. (2016) found that positive outcomes enhanced binding when both the valence and the occurrence of outcomes were unpredictable. However, the effect of valence was absent when the outcome occurrence was unpredictable and the valence was predictable. In order to re-examine the influence of outcome valence thus, we also varied the auditory outcomes of actions as pleasant versus unpleasant tones as in Barlas and Obhi (2014).

We predicted that intentional binding and FoC would be gradually enhanced as the choice-level increased from one to four (Barlas & Obhi, 2013; Barlas et al., *under review*). Regarding the influence of outcome valence, our prediction was that valence would not influence binding (Barlas et al., *under review*), but that pleasant outcomes would enhance the FoC. Importantly, we conjectured that greater internal processing in free actions would be reflected in response times (RTs) and subjective effort ratings such that RTs would be longer and effort ratings would be higher with increased choice-level. We did not, however, formulate specific predictions about whether effort ratings would be related to intentional binding or FoC ratings.

2. Method

2.1. Participants

In total, 44 undergraduate students (14 males, 1 left-handed, M_{age} = 18.86, SD = 1.56) from Wilfrid Laurier University took part in the study. The sample size was determined based on a previous study by Barlas and Obhi (2013) which recruited 22 participants and examined the effect of choice-level on intentional binding. Our post hoc calculation of sample size using *GPower 3.1.* (Faul, Erdfelder, Buchner, & Lang, 2009) would have also suggested 22 participants per group (effect size = 0.39 based on Barlas & Obhi, 2013; alpha = 0.05; power = 0.90). Participants were randomly assigned to either one of the interval estimation or the FoC rating tasks. All participants had normal or corrected-to-normal vision and had no hearing problems. The study was approved by the Research Ethics Board of Wilfrid Laurier University and participants gave written informed consent prior to beginning the study. Students received course credit for participation.

2.2. Apparatus and stimuli

The experiment was developed using Superlab 4.5 (Cedrus Corporation, USA) software and run on a Dell personal computer (3.07 GHz). Participants sat approximately 60 cm away from a 20-inch monitor (resolution: 1600 × 1200). Presentation of all stimuli was centered on a white background. Responses were made on a 5-key