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The Influence of Freedom and Choice in Action Selection and the Valence of Action-outcomes on the Sense of Agency

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Abstract

Sense of agency (SoA) refers to the subjective experience that one is the author of their actions and the ensuing outcomes of these actions. Previous research have suggested that both sensorimotor processes and high level inferences can contribute to the SoA. In five experiments, the present thesis examined the effects of action selection processes and the valence of action-outcomes on the SoA. The majority of these experiments measured the SoA by obtaining both subjective feeling of control (FoC) judgments over the action-outcomes, and assessing the size of intentional binding. Intentional binding refers to the perceived temporal attraction between actions and their outcomes, and has been suggested as an implicit measure of the SoA. Experiment 1 manipulated the number of action alternatives as low, medium, and high and examined the effect of choice-level on intentional binding. The results showed that binding was strongest when participants had the maximum number of alternatives, intermediate when they had medium choice-level, and lowest when they had no choice. Experiment 2 recruited western and non-western participants and focused on the impact of pleasantness of action outcomes on both intentional binding and FoC judgment. The results revealed that both western and non-western groups showed greater FoC ratings for the pleasant compared to unpleasant outcomes. Moreover, for the western group only, binding was stronger for pleasant compared to unpleasant outcomes. In Experiment 3, participants performed freely selected and instructed actions, which could produce pleasant or unpleasant outcomes. The results revealed stronger binding and higher FoC ratings in the free- compared to instructed-choice condition. Additionally, FoC ratings were higher for the pleasant compared to the unpleasant outcomes. Similarly, Experiment 4 varied the choice-level between one (instructed), two, three, and four alternatives while the outcome of any choice could be pleasant or unpleasant. The results showed that binding was stronger in the four-choice condition compared to one-, two-, and three-choice conditions, while FoC ratings were systematically increased as the choice-level varied from one to four, and were higher for pleasant compared to unpleasant outcomes. In Experiment 5, participants were primed with either action or neutral images and performed either free or instructed actions. Free actions could be preceded by either neutral (neutral-free) or action primes (primed-free), and instructed actions indicated performing either prime-compatible or prime-incompatible actions. The findings showed that both binding and FoC ratings indicated stronger SoA in the neutral-free condition compared to all remaining modes of action selection. Moreover, these two measures of the SoA were significantly correlated. The overall results from these studies indicate that situational factors surrounding actions determine the contribution of predictive, prospective, and retrospective mechanisms to intentional binding and subjective judgments of agency. Among these factors, the present thesis highlights that one's freedom in action selection and the availability of various action alternatives can strongly influence the SoA.

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List of Abbreviations

ACC	Anterior Cingulate Cortex
AG	Angular Gyrus
ANOVA	Analysis of Variance
BOLD	Blood-Oxygen-Level Dependent
FoC	Feeling of Control
DLPC	Dorsolateral Prefrontal Cortex
EBR	Eye Blink Rate
EMG	Electromyography
IPC	Inferior Parietal Cortex
IPL	Inferior Parietal Lobe
PET	Positron Emission Tomography
PFC	Prefrontal Cortex
RCZ	Rostral Cingulate Zone
RP	Readiness Potential
RT	Response Time
SD	Standard Deviation
SEM	Standard Error of the Mean
SMA	Supplementary Motor Area
SoA	Sense of Agency
tDCS	Transcranial Direct Current Stimulation
TMS	Transcranial Magnetic Stimulation
TPJ	Temporo-Parietal Junction

Chapter 1

General Introduction

1.1 The sense of agency

Sense of agency (SoA) refers to the subjective experience that one is the author of their actions and the ensuing outcomes of these actions (Dewey & Knoblich, 2014; Gallagher, 2000; Haggard & Chambon, 2012; Haggard & Tsakiris, 2009). This experience is a crucial aspect of self-consciousness; it not only entails the distinction between one's self and others as "the actor" but also conveys the sense of having control over what one's actions change in the environment. When we switch on a light, for example, we unquestionably know that the lightening is changed by our pressing the switch.

The SoA has important implications in morality and taking responsibility for one's actions (Haggard & Chambon, 2012; Haggard & Tsakiris, 2009), and it is closely linked to the notion of *free will* (Aarts & van den Bos, 2011; Haggard, Cartledge, Dafydd, & Oakley, 2004; Haggard, Clark, & Kalogeras, 2002; Haggard, 2008). Aside from the influence of SoA on responsibility and morality, it is imperative to understand the very nature of how we experience the SoA. Most of the time, the SoA in our daily routine of actions is so pervasive and diffused in ourselves that we do not reflect on our authorship of our actions or their consequences. In simple terms, we just know we are the actors who control external events occurring through our actions. There are times, however, that our agentic experience is distorted when we lose control over what action to take or when the consequences of our actions conflict with our intentions. The SoA, therefore, is a vulnerable phenomenon; it can be amenable to several factors and even fail to inform us of who is in control of the actions. This has been shown in both healthy individuals and several psychological and neurological disorders. For instance, individuals with no medical conditions can experience anomalous SoA when the source of actions or outcomes is ambiguous (Aarts, Custers, & Wegner, 2005; Haggard et al., 2004; Wegner & Wheatley, 1999). Moreover, disturbances of the SoA such as feeling a lack of control or misattributing agency have been observed in several disorders such as schizophrenia (Farrer et al., 2004; Frith, 2005; Haggard, Martin, Taylor-Clarke, Jeannerod, & Franck, 2003; Jeannerod, 2009; Kircher & Leube, 2003; Werner, Trapp, Wüstenberg, & Voss, 2014), motor conversion disorder (Kranick et al., 2013), obsessive compulsive disorder (Belayachi & Van der Linden, 2010; Belayachi & Van Der Linden, 2010), and anarchic hand syndrome (Blakemore, Wolpert, & Frith, 2002).

Since the late 1990s, therefore, the quest to understand how the SoA comes about and what specific mechanisms are affected in the above-mentioned disorders have sparked great interest in both psychology and neuroscience domains of research. As is the case with other aspects of self-consciousness, the SoA is a difficult topic of study due to its subjective nature. Thus, the scientific investigation of the SoA requires careful establishment of the relevant concepts and theoretical frameworks as well as appropriate experimental designs and measures. The following sections provide a brief overview of these components pertaining to the examination of the SoA. The survey will begin with introducing the conceptualization of the SoA, which identifies the levels at which the SoA is experienced. The next section will then discuss how the SoA has been measured in experimental settings based on the changes in one's perception of their actions and the outcomes of these actions. These measures have been used extensively to test the accounts of the mechanisms of the SoA, which are presented in the following section. We shall see that the nature of the SoA is multi-faceted, and there are numerous factors that contribute the subjective experience of actions including motor planning and control mechanisms, prior thoughts, high level inferences, and various situational cues. The last section is devoted to the scope of the present dissertation, which mainly focuses on the role of freedom and choice level in action selection, and the nature of the consequences of actions.

1.2 Conceptualization of the SoA

As noted before, we commonly experience the SoA in the form a tacit and unquestioned state of a phenomenon. According to the recently developed two-level account of the SoA (Bayne & Pacherie, 2007; Synofzik, Vosgerau, & Newen, 2008), this experience is described as the low level, non-conceptual, and pre-reflective SoA (Gallagher, 2000, 2007, 2011). At a higher level, the SoA is experienced through the reasoning that incorporates retrospective judgments and inferences. The high level SoA is thus conceptual and reflective in nature.

Although the distinction between the low and high levels of the SoA has provided a conceptual framework, it has also raised questions regarding how to measure these levels and the potential differences between the underlying mechanisms. Regarding the measures of the SoA (see section 1.3), it was contended that the low level SoA could be indexed by implicit measures while explicit self-reports would quantify the higher level SoA. Furthermore, it was proposed that low level SoA emerges from sensorimotor processes that operate mainly prior to the movement by producing the motor commands and the anticipations of the consequences of the movement (see section 1.4.1., Blakemore et al., 2002; Frith, Blakemore, & Wolpert, 2000; Frith, 2005). The high level SoA, on the other hand, was suggested to rely on inferences drawn from the observation of actions and their outcomes as well situational cues (see section 1.4.2, Bayne & Pacherie, 2007; Moore, Middleton, Haggard, & Fletcher, 2012; Obhi & Hall, 2011; Synofzik et al., 2008; Wegner & Wheatley, 1999; Wegner, 2003, 2004).

However, accumulating research to date has shown that the relationship between the low and high levels of the SoA and the sensorimotor versus inferential processes, respectively, might not be straightforward. Indeed, recent findings and theorizing suggest that, low-level and high-level agency can be influenced by sensorimotor or inferential processes. Before reviewing these processes and the relevant research, it is important to conceive the measures that are most commonly employed in the literature.

1.3 Measuring the SoA in experimental settings

The methodologies of the relevant research have employed both explicit/direct and implicit/indirect procedures to measure the SoA. The former are concerned with conscious self-reports about subjective control and agency attribution. The implicit measures, on the other hand, rely on changes in subjective perception of the timing of actions and their outcomes as well as on the perceived intensity of sensory outcomes.

1.3.1 Explicit/Direct measures

One way to measure the SoA is to directly obtain one’s self-reflection on their sense of control or authorship. These explicit measures thus most commonly require participants to rate on a scale (e.g., a 10-point Likert scale) to indicate how much control they feel over action outcomes (e.g., Balslev, Cole, & Miall, 2007; Barlas & Obhi, 2014; Ebert & Wegner, 2010; Linser & Goschke, 2007; Metcalfe & Greene, 2007; Sato & Yasuda, 2005; Wenke, Fleming, & Haggard, 2010) or over their actions (e.g., Sebanz & Lackner, 2007; Wegner, Sparrow, & Winerman, 2004). Additionally, in the contexts where the source of the action-outcomes is rendered ambiguous, participants are asked to make direct judgments about the cause (i.e., me, computer, or a confederate) of the observed outcomes of actions (e.g., Aarts, Custers, & Marien, 2009; Aarts, Custers, & Wegner, 2005; Dijksterhuis, Preston, Wegner, & Aarts, 2008; Spengler, von Cramon, & Brass, 2009; Wegner & Wheatley, 1999).

1.3.2 Implicit/Indirect measures

Administration of the explicit measures based on self-report has been suggested to be highly prone to contamination by issues such as social desirability, impression management, and the limits of introspection on the part of participants (Metcalfe & Greene, 2007; Obhi, 2012; Schüür & Haggard, 2011). Alternative methodologies were then employed to include indirect measures to overcome these issues with the explicit measures. Two such indirect measures are sensory attenuation and intentional binding.

1.3.2.1 *Sensory attenuation*

Sensory attenuation refers to reduced perception of the sensory outcomes produced by self-generated actions (Blakemore, Frith, & Wolpert, 1999; Blakemore, Wolpert, & Frith, 1998, 2000; Blakemore, 2003; Hughes, Desantis, & Waszak, 2013; Macerollo et al., 2015; Weiss, Herwig, & Schütz-Bosbach, 2011; Weiss & Schütz-Bosbach, 2012). Sensory attenuation is proposed to rely on the processes involved in motor preparation. More specifically, models of motor control system (Blakemore et al., 2002; Frith et al., 2000; Wolpert, Ghahramani, & Jordan, 1995; Wolpert, 1997) suggest that before the movement takes place, a copy of the motor command is sent to the so called forward model (see Section 1.4.1) which produces the predictions towards the sensory consequences of the movement. It is also proposed that these predictions are then compared to the actual outcomes of the movement, and sensory attenuation is suggested to result from the matching between predicted and actual outcomes (Blakemore et al., 1998, 2000; Frith et al., 2000). One common example is that self-tickling is experienced as less intense compared to being tickled by someone else (Blakemore et al., 1998, 2000). Sensory attenuation therefore enables the distinction between self and other generated actions, and is suggested to be a low-level sensory measure of the SoA (Synofzik et al., 2008).

Sensory attenuation can be measured by its electrophysiological correlates or behaviorally by obtaining perceived intensity of sensory stimuli. The most prominent electrophysiological marker of sensory attenuation is the N1 potential, which is found to be reduced in response to a self-generated auditory stimulus relative to when the same stimulus is externally generated (Bäß, Jacobsen, & Schröger, 2008). Reduction in N1 amplitude has also been demonstrated when the stimuli are produced by voluntary compared to involuntary [e.g., Transcranial Magnetic Stimulation (TMS) induced] movements (Timm, SanMiguel, Keil, Schröger, & Schönwiesner, 2014). Additionally, sensory outcomes produced by their associated actions were shown to yield N1 attenuation more strongly than those that are incongruent with the actions (Hughes et al., 2013; Kühn et al., 2011). Importantly, studies with disorders have shown that N1 attenuation was reduced or absent in schizophrenia (e.g., Ford, Mathalon, Kalba, Marsh, & Pfefferbaum, 2001; Ford, Mathalon, Heinks, et al., 2001) and in patients with psychogenic movement disorder, who report having reduced or no control over their movements (Macerollo et al., 2015).

Behavioral studies have provided further evidence that causal beliefs can influence the perceived loudness of outcome tones. It was found, for instance, that perceived loudness of the tones was reduced when participants believed that the tones were produced by their actions as opposed to by another person (Desantis, Weiss, Schütz-Bosbach, & Waszak, 2012).

In sum, previous research suggests that sensory attenuation can be used as an implicit marker of the SoA and is prone to be influenced by both sensorimotor processes and causal beliefs.

1.3.2.2 *Intentional binding*

Another implicit measure of the SoA relies on the perceived times of actions and their effects. In their seminal study, Haggard et al. (2002) measured the perceived times of actions and their outcomes while participants made voluntary key presses and passive (TMS induced to motor cortex) movements as they viewed a conventional clock (Libet, Gleason, Wright, & Pearl, 1983) on the screen. These key presses would sometimes produce a tone after 250 ms delay, and the association between key presses and tones was varied using baseline and operant conditions. In one block of the baseline condition (action-only), participants made a key press at a time of their choosing while fixating a rotating clock-hand on an on-screen clock. The key press did not produce any tone and participants judged the onset time of their key press by reporting the position of the clock-hand at the time of their movement. In a second block of the baseline condition (outcome-only), participants passively listened for a tone in each trial and judged the onset of the tone. In the operant conditions, the key presses would always produce a tone after a 250 ms delay and in separate blocks of trials, participants judged either the onset time of the key press or the tone. In this way, the authors could calculate the perceptual shifts in the times of key presses and tones across baseline and operant conditions (i.e., by calculating the difference between the judgment errors across these two conditions for key presses and tones). Interestingly, examination of these shifts showed that key presses in the operant voluntary condition were perceived to be occurring later (closer to the tone). In contrast, the onset of the tones was perceived earlier (closer to the key press). The perceived times of key presses and tones, therefore, were attracted towards each other in the voluntary actions (see Figure 1.1). However, this temporal attraction effect was not observed for the TMS induced passive movements. Haggard et al. (2002) suggested that perceived temporal attraction between actions and their outcomes was distinct to the voluntary actions. The authors thus coined the term *intentional binding* to refer to this effect.

Since then intentional binding has received great attention of the relevant research to explore its relationship with the SoA. Although the clock paradigm has been used quite frequently, an alternative procedure to measure the intentional binding effect was also developed. This procedure involves obtaining the perceived duration estimates of the actions-outcome interval (Caspar, Cleeremans, & Haggard, 2015; Ebert & Wegner, 2010; Engbert, Wohlschläger, & Haggard, 2008; Moore & Haggard, 2010; Moore, Wegner, & Haggard, 2009; Obhi, Swiderski, & Farquhar, 2013). Notwithstanding the type of the procedure (i.e., the clock or the interval estimation paradigm), the purported link between intentional binding and the SoA is that greater perceptual shifts binding the times of actions and outcomes, as well as shorter estimations of the action-outcome interval, imply a stronger SoA (e.g., Engbert, Wohlschläger, Thomas, & Haggard, 2007; Ku, Brass, Haggard, & Kühn, 2012; Moore & Obhi, 2012; Wenke & Haggard, 2009).

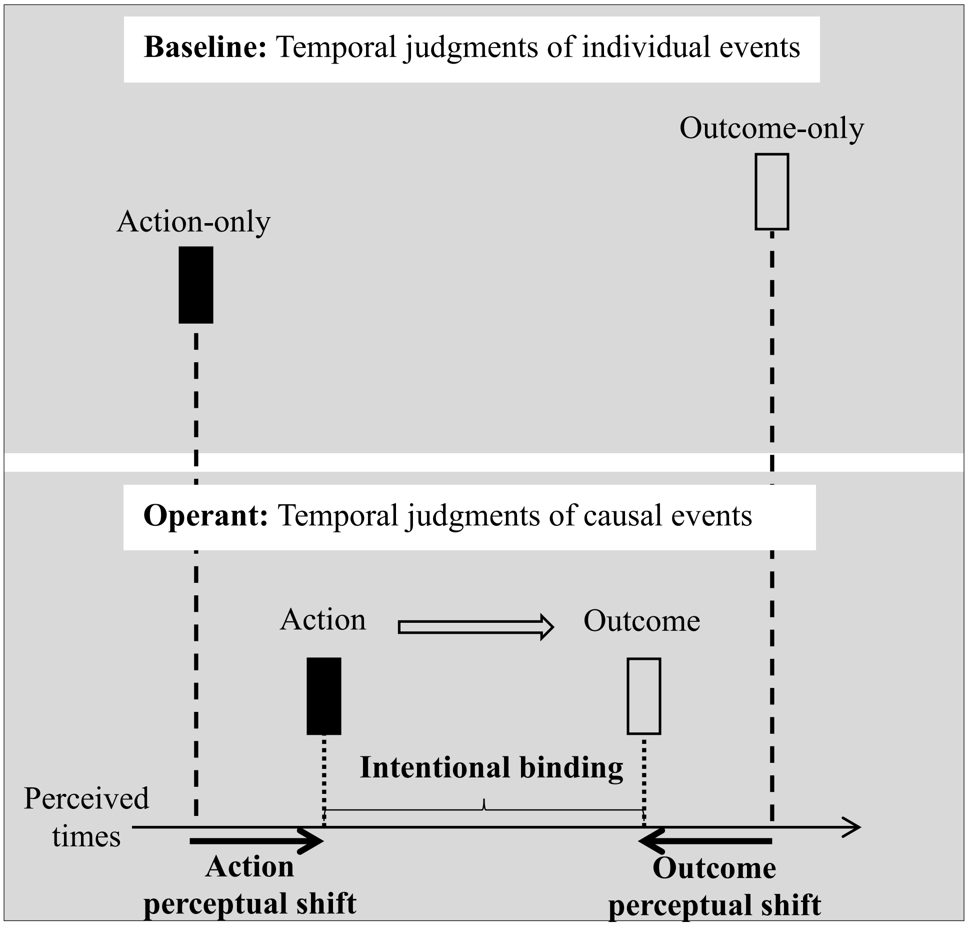

Figure 1.1 Demonstration of the intentional binding effect. In the baseline conditions, actions and outcomes occur independently. That is, in the action-only condition participants press a key which does not produce any outcome and they judge the onset time of their key press. In the outcome-only condition participants passively observe the outcomes (e.g., tones) and judge the onset of the outcomes. In the operant conditions, participants' actions always produce the outcomes and they judge the onset times of either their actions or the outcomes of these actions. Perceptual shifts for actions and outcomes are calculated by subtracting the

judgment errors in the operant conditions from the corresponding baseline conditions for each judged event (e.g., action and outcome). In a typical binding effect, these shifts demonstrate that the perceived times of actions and their outcomes are shifted towards each other.

Studies using these paradigms have further investigated whether intentional binding could indeed be specific to self-generated actions. In this regard, one line of evidence favors the intentional binding effect as a reliable measure of the self-agency. Haggard and Clark (2003), for example, compared the intentional binding effect between voluntary movements and movements that were intended but the execution of which was disrupted by TMS. Replicating the results of the previous study (Haggard et al., 2002), they observed the binding of actions and outcomes in voluntary movements. When these movements were disrupted by TMS, however, a reversal of intentional binding was found. That is, the perceived times of movements and resulting outcome tones were shifted away from each other (i.e., a repulsion effect). These results suggested that the intentional binding effect required not only the presence of intentions but also the successful execution of intended movements. The same repulsion effect was also observed, particularly on the perceived times of outcome tones, when participants themselves inhibited their intended actions (Haggard, Poonian, & Walsh, 2009).

Further research provided evidence that intentional binding can be influenced by several agency related cues. Stronger binding of actions and outcomes was reported, for example, when one believed themselves as the source of the action-outcomes (Desantis, Roussel, & Waszak, 2011), with positive or pleasant compared to negative outcomes

(Barlas & Obhi, 2014; Takahata et al., 2012; Yoshie & Haggard, 2013), and when the number of available action alternatives is at maximum within a specific context (Barlas & Obhi, 2013).

Studies examining aberrant SoA in certain disorders have also reported that the intentional binding effect was reduced in high functioning autism spectrum disorder (Sperduti, Pieron, Leboyer, & Zalla, 2013) and motor conversion disorder (Kranick et al., 2013) while it was found to be exaggerated in schizophrenia (Synofzik & Voss, 2010; Voss et al., 2010). Finally, recent research on the brain mechanisms behind this effect suggests the involvement of pre-supplementary motor area (pre-SMA). Accordingly, disrupting this area by theta-burst TMS (Moore, Ruge, Wenke, Rothwell, & Haggard, 2010b) and by transcranial direct current stimulation-tDCS (Cavazzana, Penolazzi, Begliomini, & Bisiacchi, 2015) have been shown to the reduce the intentional binding effect.

Although these findings lend support to the view that intentional binding is strongly associated with the SoA, another line of evidence has challenged its specificity to self-generated actions. One counter notion is that intentional binding might simply reflect the perception of causality between two events (Buehner & Humphreys, 2009; Buehner, 2012). Another line of research have shown that the size of binding was indifferent between self-generated and observed actions (Moore, Teufel, Subramaniam, Davis, & Fletcher, 2013; Poonian & Cunnington, 2013; Wohlschläger, Haggard, Gesierich, & Prinz, 2003; but see Engbert et al., 2007). One interpretation of these findings is that there might be overlapping mechanisms through which agency is inferred in self- and other-generated actions (Moore et al., 2013; Poonian & Cunnington, 2013).

The resolution of the debate whether intentional binding can merely be related to self-agency requires further investigation. At the moment, however, intentional binding remains a promising phenomenon in SoA research which could further elucidate its underlying processes and relationship with the SoA (see Moore & Obhi, 2012, for a review of intentional binding).

1.4 Underlying mechanisms of the SoA

An important question probed by the relevant research is concerned with the underlying mechanisms that give rise to the SoA. On this line, two main streams of processes have been suggested to play important roles in influencing the subjective experience of agency. These processes are described under the terms of predictive (sensory-motor) and postdictive (inferential) accounts. Briefly put, the predictive account is based on the computational models of motor control mechanisms that are responsible for the acquisition and control of movements by calculating the sensory consequences of these movements. Importantly, the predictive account is heavily dependent on the processes that occur before the movement (Blakemore et al., 2002; Frith et al., 2000; Frith, 2005; Wolpert et al., 1995; Wolpert, 1997). The postdictive account, on the other hand, relies more strongly on the post-movement processes that operate on the perception of causality and inferences drawn upon the observation of both the movement and its outcomes (e.g., Wegner & Wheatley, 1999; Wegner & Sparrow, 2004; Wegner, 2004). Initially, these two streams of processes were viewed as (virtually) mutually exclusive in terms of how they address the underlying mechanisms of the SoA. Recent findings, however, have resulted in agreement that both streams of processes can influence the SoA and the degree of their contribution is determined on contextual and various other factors (Desantis, Weiss, et al., 2012; Moore & Fletcher, 2012; Moore, Wegner, et al., 2009; Synofzik, Vosgerau, & Lindner, 2009; Synofzik, Vosgerau, & Voss, 2013).

1.4.1 The role of predictive processes

As noted above, the predictive account of the SoA emerged out of popular computational models of motor control system (Blakemore et al., 2002; Frith et al., 2000; Wolpert et al., 1995; Wolpert, 1997). According to the so called comparator model (see Figure 1.2), motor learning and motor control are managed by the coupling of two main internal models, namely the inverse and forward models, and the three comparators that hold various functions. The major role of the inverse models is to issue the motor command to reach the desired state of the body in accordance with the goals of the agent. Once the motor command is issued, the efferent copy of this command is simultaneously sent to the forward models. The main function of the forward models is to predict the post-movement state of the body and the consequences of the movement. At this point, the role of the comparators becomes critical. The first comparator between the predicted state and the desired state informs the inverse models in case of a discrepancy so that any required adjustments to the motor planning can be performed before the movement takes place. The second comparator between the desired state and actual state, similarly, serves to tune the functioning of the inverse models for the improvement of motor learning of new actions. Finally, the third comparator detects the discrepancies between the predicted state and the actual state, and signals the outcome of this comparison back to the forward models. This comparison is crucial for two reasons. First, it helps the forward models improve their functioning in case of a mismatch between predictions and actual outcomes. Second, and more importantly, the result of this comparison is suggested to allow the distinction between self and other produced actions. More clearly, the greater the discrepancy between the predicted and actual states the more likely that agency is attributed to the others or the experience of self-agency is weakened.

In support of the role of internal models on the SoA, Sato and Yasuda (2005) manipulated the congruency between actions (left and right key presses) and outcomes (high and low pitch tones) by rendering the outcomes unpredicted in terms of their timing and frequency. Their results showed the subjective ratings of being in control of the outcomes were reduced when the timing and the frequency of these outcomes were incongruent with the previously learned action-outcome associations. Furthermore, in a second experiment, they showed that participants could experience illusory sense of control over prediction-matching outcomes when in reality they were externally produced. These results suggested that the matching between predicted and actual outcomes could remarkably influence one's subjective feeling of control (FoC).

In a similar vein, Linser and Goschke (2007) used subliminal priming of action-effects and examined the influence of congruency between these primes and actual action-effects on participants' subjective FoC over the outcomes. The results showed that the FoC was greater when the primed effects were compatible with the actual outcomes, suggesting that unconscious modulation of the internal predictions could influence the subjective FoC. Further support to the role of the predictive mechanisms came from a study which showed that deafferented patients failed to discriminate between self and other generated cursor movements on the screen in the absence of visual feedback ,while the control group of healthy participants was better able to do so (Balslev et al., 2007).

These results highlighted the contribution of the matching between predicted state of the body and the proprioceptive input.

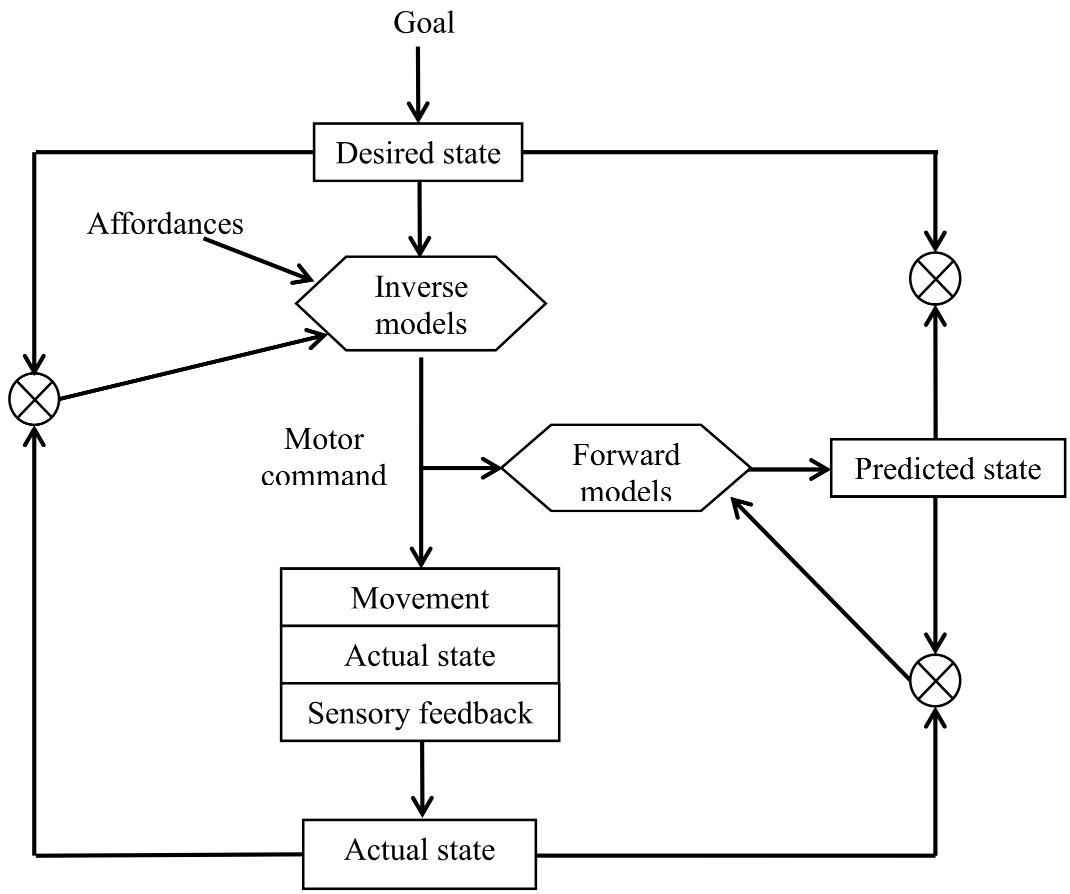

Figure 1.2 The comparator model, adapted from Frith et al. (2002).

Although the role of action control mechanisms and internal models appears to be indispensable in giving rise to the SoA, the predictive account cannot explain, for instance, the cases in which one can still experience some degree of authorship when the pre-movement predictions do not match the actual outcomes. The main drawback of the predictive account is that it does not, in its basic form, incorporate the contribution of other potential cues such as background beliefs, conscious judgments, and inferential processing linked to the SoA (for a critical review see, de Vignemont & Fourneret, 2004; Pacherie, 2008; Synofzik et al., 2008, 2013).

1.4.2 The role of postdictive processes

The postdictive (inferential) account is based on the Humean analysis on the perception of causality (Hume, 1888). Within this analysis, we perceive two events as causally related when they are temporally contingent and consistent. Along the same lines of causality and our interpretation of it, Wegner and Wheatley (1999) suggested that we infer that our actions or conscious thoughts are the cause of external events when (1) our thoughts or intentions occur before the observed events, (2) our intentions are consistent with the observed events, and (3) there are no other agents that could potentially cause the same events. As such, this account emphasizes the contribution of higher level inferences drawn retrospectively based on our observations of our actions and following events (see also, Wegner & Sparrow, 2004; Wegner, 2004).

Support for this view came from the studies demonstrating that the SoA could occur even when the sensory-motor predictive signals are lacking. Wegner and Wheatley (1999), for example, conducted a study in which the participant and confederate simultaneously performed cursor movements on the screen. In some trials, the image on which the cursor would stop was presented through the headphones. When the primed image matched the actual image where the cursor was moved to, participants claimed authorship over these movements. Importantly, participants' illusory judgment of agency occurred despite the fact that it was the confederate who actually caused the movements.

In a similar vein, another study showed that participants could experience vicarious SoA over someone else's movements (Wegner et al., 2004). In this study, participants viewed their mirror reflection while the confederate stood behind the participant positioning their arms in the place of the participant's arms. In the mirror thus, it looked as if the confederate's arms belonged to the participant. Through headphones, movement instructions were delivered to both the participant and the confederate. Examination of the participant's judgments of how much control they felt over the mirror reflected movements revealed that the experience of agency was enhanced when the instructions and actual movements were the same.

Taken together, these results supported the notion that the SoA is influenced by prior thoughts and situational cues. Nonetheless, the postdictive account too has its own inadequacies as a full-fledged account of the SoA. In essence, the main problem is that it merely emphasises post-movement cues and thoughts, leaving no role for internal pre-movement processes. It cannot explain thus, how in everyday life we experience the low level, pre-reflective SoA (see Section 1.2) without having to rely on high level judgments and inferences.

1.4.3 The interplay between predictive and postdictive processes

The above mentioned drawbacks of predictive and postdictive accounts have led to the emergence of a new approach that combined the both processes into a unifying framework. This framework proposed a Bayesian model of cue integration process that estimates the weighting of both internal (sensory-motor, predictive) and external (postdictive, inferential) cues that are available in the context of actions. According to this model, the weighting of these cues determines their reliability and thus their differential influence on the SoA (Farrer, Valentin, & Hupé, 2013; Moore & Fletcher, 2012; Synofzik et al., 2013; Wolpe, Haggard, Siebner, & Rowe, 2013).

Moore and Haggard (2008), for example, manipulated the probability of action-effects to occur as high (75%) and low (50%), and measured the intentional binding effect using the clock paradigm. Participants made voluntary key presses and reported the onset time of either their key press or the auditory tone. The results showed that in the high probability condition, the perceived times of key presses were still shifted later in time when these key presses did not produce the tone. When the probability was low, on the other hand, perceptual shifts were still observed for the trials in which key presses produced the tone. The authors suggested that the former set of results pointed to the role of predictive processes while the latter indicated the contribution of retrospective inferences.

In another study, participants were primed with auditory outcomes (low or high pitch) of voluntary and involuntary movements (Moore, Wegner, & Haggard, 2009). These primes could be either congruent or incongruent with the actual outcomes and participants estimated the temporal delay between their movements and auditory outcomes. It was found that binding was stronger in voluntary than involuntary movements and when the primes were congruent with the outcomes than they were incongruent. Importantly, however, the influence of prime compatibility was stronger in the involuntary condition compared to the voluntary condition. These findings indicated that when predictive cues are absent (as in the involuntary condition), external cues (i.e., the compatibility of the primes) can become more reliable and therefore influence the SoA (see also Stenner et al., 2014).

Studies probing the neural structures associated with the SoA also support the multiple cue integration view. These studies suggest that a wide network of brain structures including the fronto-parietal network (Chambon, Wenke, Fleming, Prinz, & Haggard, 2013; Dogge, Hofman, Boersma, Dijkerman, & Aarts, 2014) is linked to the SoA. Among these areas, the cerebellum was proposed to be engaged in pre-motor predictions of the consequences of actions (Blakemore, Frith, & Wolpert, 2001; Blakemore et al., 1998) and dorsolateral prefrontal cortex (DLPC) was related to voluntary action initiation (Jahanshahi et al., 1995) and action monitoring (Rowe, Hughes, & Nimmo-Smith, 2010).

Additionally, right inferior parietal lobe (IPL) was found to show increased activity when visual feedback is incongruent with the intended movement (David, 2010; David et al., 2007; Tsakiris, Longo, & Haggard, 2010). Accordingly, it was found that repetitive TMS applied over the inferior parietal cortex (IPC) resulted in rejection of self-agency for unperturbed feedback of the movements (Ritterband-Rosenbaum, Karabanov, Christensen, & Nielsen, 2014), suggesting that increased activity in this area signals the discrepancies between intended and actual outcomes of actions. Detection of such discrepancies and attribution of agency to the others was found to be particularly associated with angular gyrus (AG) in the right IPL (Farrer & Frith, 2002; Farrer et al., 2008; Miele, Wager, Mitchell, & Metcalfe, 2011; Spengler et al., 2009). In contrast, pre-SMA and rostral cingulate zone (RCZ) are suggested to mediate self-generated movements and action selection (Forstmann et al., 2008; Forstmann, Brass, Koch, & Cramon, 2006; Miele et al., 2011; Tsakiris et al., 2010). As noted before, the pre-SMA is also suggested to be a major area underlying intentional binding (Cavazzana et al., 2015; Kühn et al., 2012; Moore et al., 2010b). Finally, conscious judgments of the degree of control over action-outcomes was linked to the increased activity in the prefrontal cortex (PFC) (Miele et al., 2011).

1.5 Present dissertation: The influence of freedom and choice in action selection and the valence of action-outcomes on the SoA

Majority of the previous studies examining the role of predictive and postdictive processes have mainly focused on the compatibility of pre-motor predictions, prior thoughts and goals with the observed action-outcomes. However, it is also fundamental to human actions that performed actions are the result of a selection process among different actions. These processes can play important role in determining the right action to achieve one's intentions. In fact, several processes can be involved in the time course between the emergence of intentions and the outcomes of performed actions.

In this regard, Pacherie (2008) proposed a comprehensive framework within which intentions are distinguished at three levels[1] based on their content and function to control and monitor human actions. According to this model, distal intentions (D-intentions) are represented at an abstract level and their realization to actions may occur within some flexible temporal delay (e.g., going to the park tomorrow). Proximal intentions (P-intentions), on the other hand, construct the representational plan of the action by integrating the conceptual information preserved in D-intentions and the current situational constraints (e.g., determining whether to walk or drive to go to the park based on time and weather constraints). Finally, motor intentions (M-intentions) are involved in

[1] Pacherie (2008) established this framework by integrating previous views that distinguished between, for instance, prior intentions and intentions-in-action (Searle, 1983), future-directed and present-directed intentions (Bratman, 1987).

the specification of the motor representations in terms of the spatial positions of the limbs to perform the action (e.g., different action plans would be programmed depending on whether one walks or drives to the park). It is important to note that both P-intentions and M-intentions can represent the selection of a specific action and the manner of action execution at different levels of specificity. Of more interest, this model also suggests that the subjective experience of agency is directly related to P-intentions and M-intentions as these levels are closely engaged in the monitoring and control of actions.

The goal of the present thesis is twofold. First, it aims to uncover how the subjective experience of agency would be influenced when one's freedom in action selection (i.e., freely selected vs. instructed) and the number of available actions are manipulated. With respect to the dynamic theory of intentions (Pacherie, 2008) mentioned above, this manipulation specifically calls upon the levels of P-intentions and M-intentions which represent the selection and execution of actions. Second, the present thesis also aims to investigate the influence of perceived valence (e.g., pleasantness) of action-outcomes on the SoA. Importantly, these two manipulations (i.e., freedom and choice-level in action selection and the outcome-valence) were attempted to be implemented in both separate and common experimental contexts.

Regarding the influence of externally perturbing the selection of actions on the SoA, Sebanz and Lackner (2007) found that FoC was reduced when external vocal instructions were incompatible with the stimulus guided actions. Under such external perturbations on action selection and execution, it was also found that participants felt stronger control when they could freely choose one of two actions compared to when they performed stimulus guided actions. These results suggested that external disturbances at the level of action selection (P-intentions) and action execution (M-intentions) can influence one's subjective experience of agency.

A different line of research has suggested that action selection processes provide prospective cues to the SoA (Chambon et al., 2013). Relevant studies in this stream examined the role of action selection processes on the SoA along the lines of fluency (i.e., effortless processing of action selection) and the source (i.e., self vs. other) of action selection. More specifically, the role of selection fluency has been examined by using subliminal and supraliminal priming of actions. The particular goal of these studies was to investigate whether the compatibility of these primes with the actions would influence the SoA (Chambon & Haggard, 2012; Damen, van Baaren, & Dijksterhuis, 2014; Sidarus, Chambon, & Haggard, 2013; Wenke et al., 2010). Overall findings of this line of research suggested that compatible action primes, when subliminally presented, increased one's FoC over the action-outcomes (e.g., Chambon & Haggard, 2012; Wenke et al., 2010). The authors of these studies suggested that compatible primes could facilitate the selection processes, which in turn enhanced the sense of being in control of the outcomes produced by fluently selected actions (see Chambon, Sidarus, & Haggard, 2014 for a review).

Studies investigating how the SoA could be influenced by self vs. other selected actions commonly included two alternative actions in their design. Wenke, Waszak, and Haggard (2009), for example, varied the timing and the choice of actions such that participants could either freely choose one of two keys or press the instructed key at a time of either their own choice or during a pre-specified interval. Across these conditions, the authors measured the size of intentional binding effect. Their results showed that the size of the binding between the perceived times of key presses and tones was greater when both the choice and timing of actions were specified by the same source, i.e., either freely selected or instructed, compared to when these dimensions were determined by different sources. The conclusion based on these results was that the SoA indexed by intentional binding could be enhanced when the decisive source of both the what- and the when-dimension of actions are the same as opposed to when different sources determine the timing and the type of actions.

Regarding the second goal of the present thesis (i.e., the influence of outcome valence on the SoA), previous studies have shown that negative action outcomes (e.g. vocalization of fear) had an attenuating effect on intentional binding compared to positive (e.g., vocalization of amusement) or neutral (a pure tone) outcomes (Yoshie & Haggard, 2013) and positive monetary gains enhanced the binding effect. Also, priming participants with positive pictures compared to neutral ones was found to increase the intentional binding effect (Aarts et al., 2012). These results have commonly been interpreted with the notion of self-serving bias (Duval & Silvia, 2002; Miller & Ross, 1975; Taylor & Brown, 1994), which refers to the stronger tendency to attribute the self as the cause of positive than negative or undesirable events.

In the present thesis, the role of action selection processes and the role of outcome valence were investigated in five experiments. The majority of these experiments measured the SoA using both the intentional binding paradigms and self-report measures of subjective control. In this way, we could observe the influence of these factors on both low SoA as purportedly indexed by intentional binding and high level of the SoA quantified by self-reports.

1.5.1 Preview of the experiments in this dissertation

The goal of Experiment 1 was to examine how intentional binding is affected when the number of action alternatives is manipulated from low (no choice) to medium and high level of choice. In the no choice condition, participants could press the pre-determined button on the response pad. In the medium-choice condition, they were free to choose among three buttons and in the high-choice condition, they were allowed to press any of the seven buttons. Participants reported the onset times of either the key presses or the outcome tones and we measured the size of binding in each condition.

Experiment 2 examined the effect of outcome valence (i.e., pleasant vs. unpleasant) on the SoA. We recruited both western and non-western participants in order to explore any potential cultural differences in the effect of outcome valence. Participants completed a modified version of the intentional binding task in which they freely selected one of two keys, which produced either pleasant or unpleasant outcomes. We measured both intentional binding and FoC ratings over the outcomes.

The goal of Experiment 3 was to investigate the influence of the origin of action selection (i.e., free vs. instructed) and the valence of the action-outcomes on both intentional binding and the FoC ratings. Participants performed either freely selected or externally instructed key presses among four options and each key press produced either a pleasant or an unpleasant auditory stimulus.

Experiment 4 examined the influence of the number of action alternatives and the outcome valence on both intentional binding and FoC ratings. Participants were either free to choose a key among two, three, or four key alternatives or had only one (externally determined) option. Each key press could randomly produce either a pleasant or an unpleasant auditory stimulus. We also obtained the subjective ratings of mental effort experienced in key selection in each condition.

The focus of Experiment 5 was the influence of freedom and fluency in action selection on the SoA. Accordingly, we used supraliminal action primes and participants performed either free or instructed actions in response to a symbolic target cue. The modes of action selection included free selections preceded by either neutral (neutral-free) or action primes (primed-free), and instructed selections required to perform either prime-compatible or prime-incompatible actions. All actions produced a tone after a jittered delay. Participants estimated the action-outcome delay and reported FoC judgments over the action-outcomes. Additionally, we obtained a subjective measure of perceived effort in action selection.

Chapter 2

Experiment 1: Freedom, Choice, and the Sense of Agency

Contents

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2.1 Abstract

The sense of agency (SoA) is an intriguing aspect of human consciousness and is commonly defined as the sense that one is the author of their own actions and their consequences. In the current study, we varied the number of action alternatives (one, three, seven) that participants could select from and determined the effects on intentional binding which is believed to index the low-level SoA. Participants made self-paced button presses while viewing a conventional Libet clock and reported the perceived onset time of either the button presses or consequent auditory tones. We found that the binding effect was strongest when participants had the maximum number of alternatives, intermediate when they had medium level of action choice and lowest when they had no choice. We interpret these results in relation to the potential link between agency and the freedom to choose one's actions.

2.2 Introduction

One of the most fundamental aspects of human actions is the capacity to choose one's actions depending on the availability of a number of action alternatives (Haggard, 2008; Nichols, 2011). This capacity, however, is bound to the environmental circumstances that determine whether the environment offers a range of action alternatives and whether one can freely choose an action among these options or perform an action that is specified by external sources. The critical aspect of free actions is that the decisions that determine *whether* to act or not, *what* action to perform, and *when* to perform an action are *self-generated* (Brass & Haggard, 2008). Although a fine-grained scientific definition of self-generated actions (also referred to as voluntary, internally generated, or endogenous) is yet to be accomplished (for a discussion on this topic see Nachev & Husain, 2010; Obhi, 2012; Passingham, Bengtsson, & Lau, 2010a, 2010b; Schüür & Haggard, 2011), one approach is to consider it as in contrast to, for example, reflexes that are primarily stimulus driven actions. It is, however, important to note that this contrast does not mean that self-generated actions are completely independent from environmental sources (Filevich et al., 2013; Schüür & Haggard, 2011). When driving from one place to another, for example, the environment determines the possible routes, the distance to be travelled on each route, and the road conditions. In this case, one's decisions on the way to the destination would be dependent on these environmental constraints although one can still freely determine *whether* to drive or not, *what* route to take, and *when* to go. In this scenario, one's self involvement in making these decisions would be reduced if someone else, or an emergency situation, required one to travel at a specific time while one could still decide on what route to take. It would be even more reduced if an external source determined all decisions including which route to take.

The critical point here is that freedom and self-generation of actions can be graded depending on the degree of self-involvement or endogenous processing (Passingham et al., 2010a, 2010b) in action selection, preparation, and execution. This is in line with the view that purports a continuum between self-generated actions and simple reflexes rather than placing the self-generated and externally influenced actions under two distinct categories (Haggard, 2008; Passingham et al., 2010a).

Although the primary aim of this chapter, as well as the present thesis, is not to propose an extensive discussion on the conceptualization of self-generated actions, the term self-generated will be used to refer to *relatively* greater freedom and self-involvement (internal or endogenous processing) that the experimental context allows compared to more constrained conditions. As exemplified above, the degree of self-involvement can vary depending on *who* determines either the type or the timing of actions. The goal of the present chapter is to further unpack the *what* dimension of actions by varying the number of action alternatives and examine how the SoA as indexed by intentional binding would be influenced by this manipulation of choice-level in action selection.

In this regard, the relationship between agency and freedom in action selection and the choice-level has been considered from various perspectives. From a broad perspective, agency and freedom are often considered to be tightly intertwined. More specifically, agency is thought to be strongest in an ‘environment of opportunities’ (Pettit, 2001). Indeed, if a person cannot freely choose a course of action, the very notion that they are an autonomous agent is undermined. Given this, it might be expected that agency and freedom are related such that increasing levels of freedom to choose a course of action correspond to increasing levels of agency. This prediction is based on the abovementioned notion of greater self-involvement and internal processing in self-generated actions that are freely selected within some level of choice space.

One relevant line of research examining the neural basis of free and instructed actions, for example, found increased BOLD (Blood-oxygen-level dependent) contrast in dorsolateral prefrontal cortex (DLPFC), inferior parietal lobe (IPL), rostral cingulate zone (RCZ), and supplementary motor area (SMA) when actions were freely selected as opposed to when they were performed as instructed (Cunnington, Windischberger, Deecke, & Moser, 2002; Filevich et al., 2013; Waszak et al., 2005). Among these areas, importantly, RCZ is suggested to be linked to free choice of varying number of action alternatives (Forstmann et al., 2008, 2006).

Greater internal processing in free actions is also supported by the computational models of action selection. One such model, called the affordance competition hypothesis (Cisek, 2007), suggests that action selection relies on dynamic processing of representations of potential actions and sensory information related to the surrounding context. According to this model, critically, the representations of potential actions are in competition with each other to go under further processing during the course of action selection. Furthermore, it is suggested that the dorsal visual system involves in specifying the potential actions while the competition process among the representations of actions takes place in the fronto-parietal cortex. The competition of these representations consists of dynamic excitation and inhibition among the populations of neurons until one reaches a threshold activity strength. Additionally, this process also computes the sensory information received from prefrontal regions and basal ganglia. Therefore, this model confirms that self-generated actions are the outcome of the internal processes involving the agent's current needs, sensory information, and the representations of potential actions.

The core idea of greater endogenous processing in free actions provides the theoretical grounds to examine how one's freedom to choose among a varying number of potential actions could influence the SoA. However, very few studies have addressed this question. Although it was not a direct examination of the link between freedom and agency, Wenke et al. (2010) assessed the subjective judgments of control when the compatibility between subliminal action primes and performed actions was manipulated in addition to varying the proportion of free versus cued trials. More specifically, participants could perform either freely selected (among two options) or cued (instructed) actions when the proportion of free trials was either high (75%) or low (25%). Additionally, subliminal action primes presented prior to the action selection could be either compatible or incompatible with the performed actions. The results showed that participants felt greater control over the outcomes when the primes were compatible with the performed actions, suggesting the effect of facilitating the action selection processes (see Chapter 6). Of more interest, the control ratings were higher when the proportion of free trials was high (75%) compared to when it was low (25%). This study suggested an intriguing link between one's freedom to choose an action and their feeling of control (FoC) over the consequences of their action.

By extension, and reducing the general idea of a link between freedom and agency to a testable laboratory task, intentional binding might also be expected to vary with differences in the degree of freedom to choose an action. Again, agency and freedom are often talked about together and the feeling of freedom has been linked to choice (e.g., Markus & Schwartz, 2010). In this light, it is interesting to note that most previous intentional binding experiments have required participants to make a pre-specified action which is followed by a sensory event such as an auditory tone. In such cases, the participant is free to select *when* to make an action, but is not free to select *which* action to make. As proposed by Brass and Haggard (2008), decisions on which action to take (*what*), the timing of executing an action (*when*), and whether or not to execute an action (*whether*) are three important components of intentional actions(see also Haggard, 2008). By simply changing the number of action alternatives that are available to participants, it is possible to parametrically manipulate the ‘environment of opportunities’ (i.e., choice) and thus ascertain the effect that the number of choice alternatives has on intentional binding. The fundamental question is, do more action alternatives produce greater levels of intentional binding than a more constrained choice set, where the agent is less involved in selecting which action to make?

To this end, in the present study we examined how agency as purportedly indexed by intentional binding (e.g., Engbert, Wohlschläger, Thomas, & Haggard, 2007; Ku, Brass, Haggard, & Kühn, 2012; Moore & Obhi, 2012; Wenke & Haggard, 2009), is affected when the number of action alternatives is manipulated. To our knowledge, this is the first study that addresses the potential relationship between freedom of action choice and the SoA and intentional binding in particular. Accordingly, in the present study participants were requested to make a key press on a seven-button response pad while watching a conventional Libet clock on the screen. They reported their perceived times of key press or the auditory tone that was produced by their key press. In the no choice condition, they were told to press only one specific button on the response pad. In the medium-choice condition, they were free to choose among three buttons and in the high-choice condition they were allowed to press any of the seven buttons. For reports of the timing of actions and effects, we employed a similar paradigm to that of Libet, Gleason, Wright, and Pearl (1983) (see also Haggard et al., 2002; Obhi, Planetta, & Scantlebury, 2009). Based on the previously surveyed views regarding the relationship between freedom, choice, and the SoA as well as the emphasis on internal processing in free actions, we predicted that intentional binding would parametrically increase from the no-choice condition to medium-choice and to high-choice conditions.

2.3 Method

2.3.1 Participants

24 right-handed participants (18 women; age range=17-22) took part in the study. All participants had normal or corrected-to-normal vision and received partial course credits for their participation. The study was approved by the Research Ethics Board of Wilfrid Laurier University, and all participants gave written informed consent prior to beginning the study. One participant's data was not included in the analyses due to not following the experimental instructions.

2.3.2 Apparatus and Procedure

The experiment was programmed in Superlab 4.5 (Cedrus Corporation, USA) and ran on a Dell personal computer (3.07 GHz). The stimuli were presented on a 20 inch monitor (1600x1200). Participants sat approximately 60 cm away from the computer monitor and the responses were recorded on a laptop by the experimenter. The experiment consisted of baseline and operant conditions in which the number of keys to press (high: 7, medium: 3, no choice: 1) and the critical event (key press, tone) that participants judged the timing were manipulated. Similar to Haggard et al.'s (2002) study, the baseline condition consisted of single events with either the key presses or the auditory tones. The key press single event condition included seven (high level of choice condition), three (medium level of choice condition), and one (no choice condition) key press choices. In the no choice condition, participants could only press the blue button centrally placed on the response pad. In the medium level of choice condition, they could choose any of the three buttons on the right side of the response pad. In the high level of choice condition, participants were free to choose any of the seven buttons on the response pad. When the critical event was the auditory tone, participants did not make any key press but only reported the time when they heard the tone. In the operant conditions, participants' key press was followed by a 1000 Hz tone (duration: 100 ms, bit rate: 160 Kbps) presented after a delay of 200 ms and they were asked to report the time of either their key press or the tone. The condition (2: baseline, operant) together with the level of action choices (3: High, Medium, No choice), and the critical event (2: Key press, Tone) in total were tested in ten separate blocks with 30 trials each (see Table 2.1 for a list of different block types). The order of the blocks was randomized across participants. At the beginning of each block, participants were informed which key or keys they were allowed to press and which of the two events' timing (key press or the tone) they were going to report. Participants completed 6 practice trials prior to the beginning of each block. Sixty practice trials in total thus were excluded from the data analysis.

Each trial began with a warning signal noting that a new trial will begin, which remained on the screen for 1 s. The fixation cross was then presented for 500 ms and followed by the display of the Libet clock (1.8 cm in diameter) with a minute hand pointing to one of 12 positions marked at 5-minute intervals. Participants were told to report their judgments between 0 (12 o'clock position) and 59, including the intermediate values. The minute hand remained stationary at the center of the screen for 500 ms and then started rotating clockwise at a 2.5 s period. In the baseline- where the single event was the key press only- and in the operant conditions, participants were told to make the key press at their own pace using their right index finger after the clock started rotating. They were instructed not to give stereotyped responses in the high and medium level of choice conditions and not to press the key at predetermined minute hand positions. In the baseline tone-only condition, participants did not make any key press but reported the onset of the tone occurred at a random time (jittered between 200 and 2000 ms) after the clock hand rotation started. The clock continued rotating for about 2000 ms after the participants reported the timing of the critical event. The perceptual times were verbally reported as minute hand positions and recorded by the experimenter on a laptop. At the end of the experiment, participants were debriefed and thanked for their participation in the study (See Figure 2.1 for a sample trial procedure).

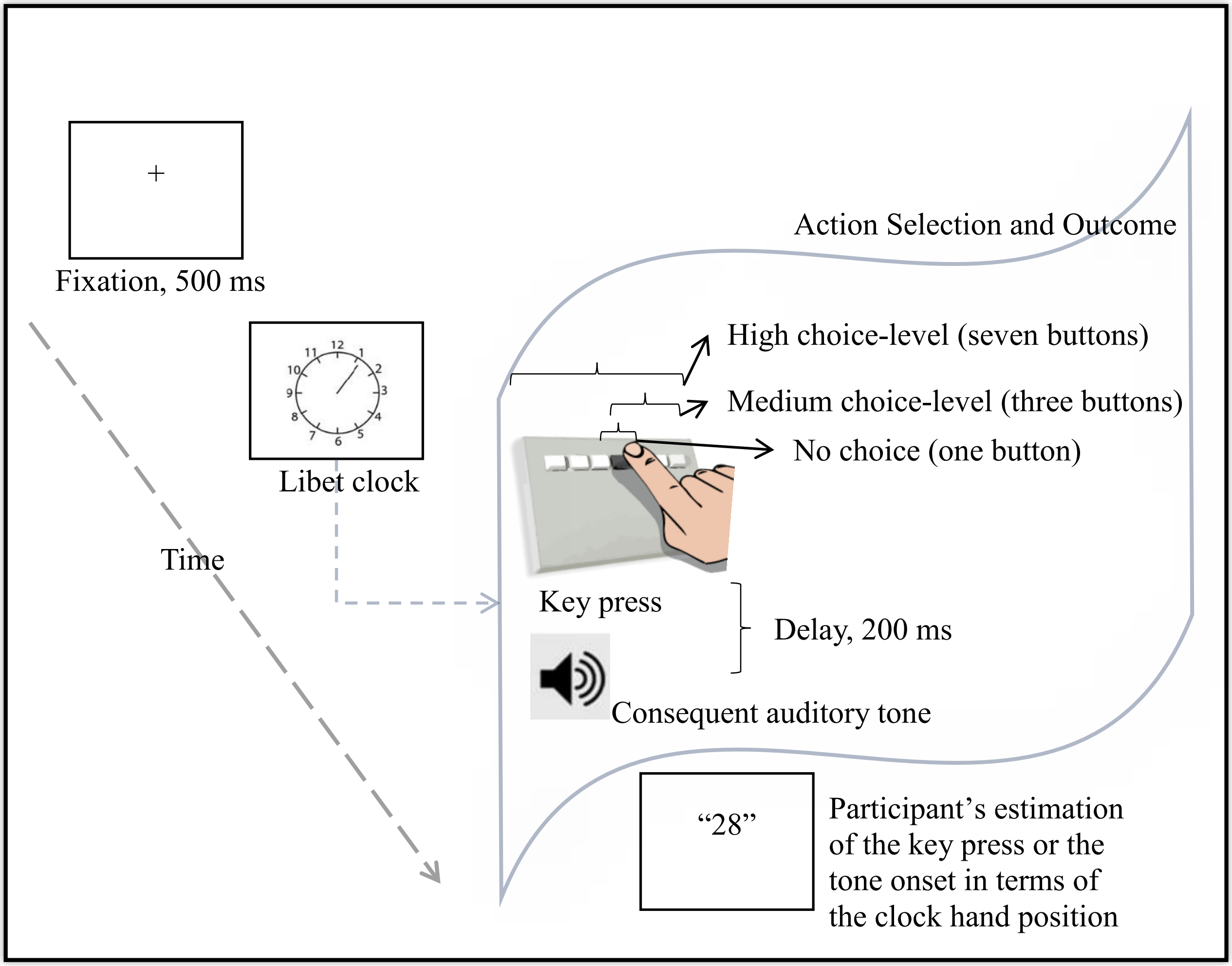

Figure 2.1 Trial procedure in the operant condition. Each trial began with a fixation cross displayed for 500 ms. Participants then made a key press at their own pace after the clock started rotating. They were told to press a specific button in the no-choice condition or select one of three (medium level of choice) or seven (high level of choice) buttons on the response pad. The key press was followed by the auditory tone after a delay of 200 ms. In the baseline condition, participants either made a key press without hearing the tone and judged the timing of their key press, or heard the tone which occurred alone and judged the timing of the tone.

2.4 Results

The experiment comprised a 2 (Condition: Baseline, Operant) x 3 (Level of choice: High, Medium, No choice) x 2 (Critical Event: Action, Tone) repeated measures design. After converting the clock hand judgments to time values in milliseconds, we calculated the judgment errors for each condition as the difference between perceived and actual times of events (Table 2.1). Trials with key press response times (RT) shorter than or equal to 500 ms and with judgment errors three standard deviations away from participant's average judgment error were excluded from the analysis. In addition, trials in which participants made a key press other than the permitted ones were removed from the data. The exclusion criteria resulted in the removal of 3.06% of all trials (range: 1-11%).

Table 2.1. Mean judgment errors in each condition. For each event and each condition, perceived times were subtracted from the actual time of the corresponding events. Asterisks indicate the judged event (i.e., the onset time of key press or tone).

Level of Choice	Individual Event	Mean Judgment Error	SD
No Choice	Key press alone	-35.96	67.85
	Key* tone	-12.68	81.19
	Key tone*	-106.12	135.21
Medium	Key press alone	-19.24	83.33
	Key* tone	-13.21	63.10
	Key tone*	-141.55	114.60
High	Key press alone	-58.19	62.18
	Key* tone	-11.34	83.65
	Key tone*	-137.73	143.22
	Tone alone	-117.44	97.56

We then obtained the perceptual shifts in terms of the difference between judgment errors between operant and the corresponding single event baseline conditions for both key press and tone judgments. For example, the perceptual shift for the high level action choice condition was calculated as the difference between the judgment errors in the operant-high-level condition from the baseline-high-level condition. Similarly, the perceptual shifts for the tone judgments were calculated as the difference between the judgment errors in each choice level-tone judgment condition and baseline-tone only condition. The positive shifts in the key press judgments and the negative shifts in the tone judgments relative to the corresponding baseline conditions demonstrate the temporal attraction, i.e. the intentional binding effect, between actions and effects (see Figure 2.2).

We performed a 3 (Level of choice: High, Medium, No choice) x 2 (Critical event: Key press, Tone) repeated measures ANOVA to examine the effect of having different number of action choices on the perceptual shifts. The analysis revealed a significant main effect of key press choice ($F(2,44)=3.36$, $p=.044$, $\eta^2 = .13$) and a significant main effect of critical event ($F(1,22)=5.15$, $p=.003$, $\eta^2 = .19$). The interaction between these factors was also significant ($F(2,44)=3.39$, $p=.043$, $\eta^2 = .13$). We predicted that binding would be least for the no choice condition, strongest for the high level of choice condition, and intermediate for the medium level condition. We thus conducted one-tailed paired samples t tests to examine the two-way interaction in more detail.

The t tests performed on the perceived times of actions revealed that when participants had high number of choices among which keys they could press, their perceptual shift in key press judgments from baseline condition was moved significantly further toward the tone compared to when they had medium level of choices (*t(*22)=2.29, *p*=.016) and to when they had no choice (*t(*22)=1.79, *p*=.043) . The difference between medium level of choice condition and no choice condition was not significant (*p*>.05).

With respect to the tone judgments, the perceptual shifts moved toward the perceived action onsets for both medium and high levels of choices. The size of the shift was greater for the medium level than the high level and it was in the opposite direction for the no choice condition. We found a significant difference in the perceptual shifts between high level of choice and no choice conditions (*t(*22)=-2.19, *p*=.020) and also between medium level of choice and no choice conditions (*t(*22)=-2.26, *p*=.017). The difference in the perceptual shifts between high and medium level of choices was not significant (*p*>.05).

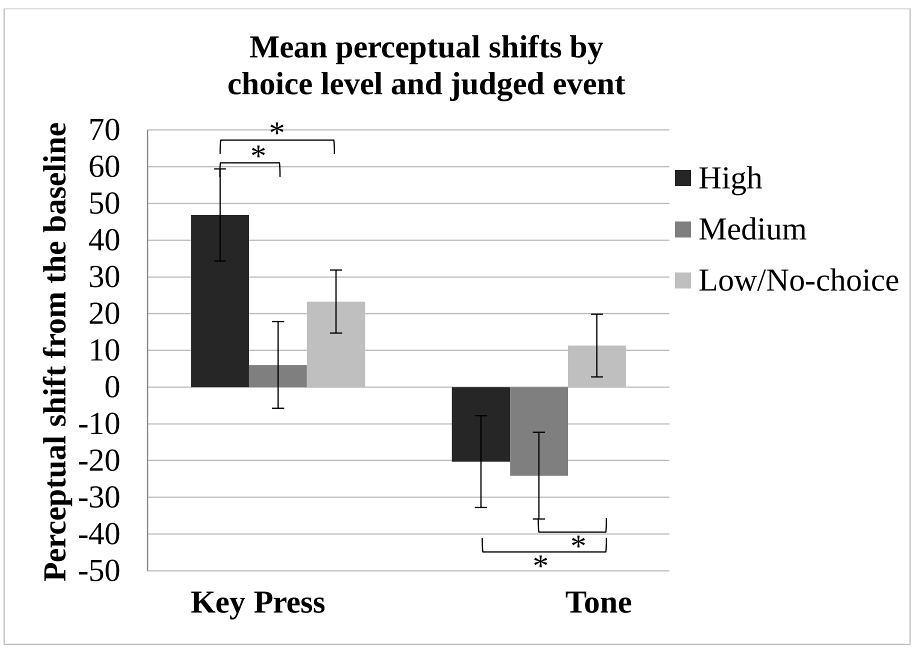

Figure 2.2 Mean perceptual shifts (difference between the judgment errors in the operant and baseline conditions) for key press and tone judgments (*p<.05). Error bars represent SEM.

We sought further the effect of choice levels on the mean overall binding which was calculated by subtracting the tone perceptual shift from the key press perceptual shift for each condition (Wenke, Waszak, & Haggard, 2009). We conducted a 3 (Level of choice: High, Medium, No choice) repeated measures ANOVA and found a significant main effect of action choice level on overall binding ($F(2,44)=3.39$, $p=.043$, $\eta^2 = .13$). As expected, we found that overall binding was strongest in the high level of action choice condition, intermediate for the medium level of choice condition, and lowest for the no choice condition (see Figure 2.3). We performed one-tailed t tests to examine the differences across the three choice levels. The results showed that overall binding in the high level of choice condition was significantly greater compared to no choice ($t(22)=1.99$, $p=.018$) condition. However, the difference between high level of choice and medium level of choice condition as well as the difference between medium level of choice and no choice conditions were not significant ($p>.05$).

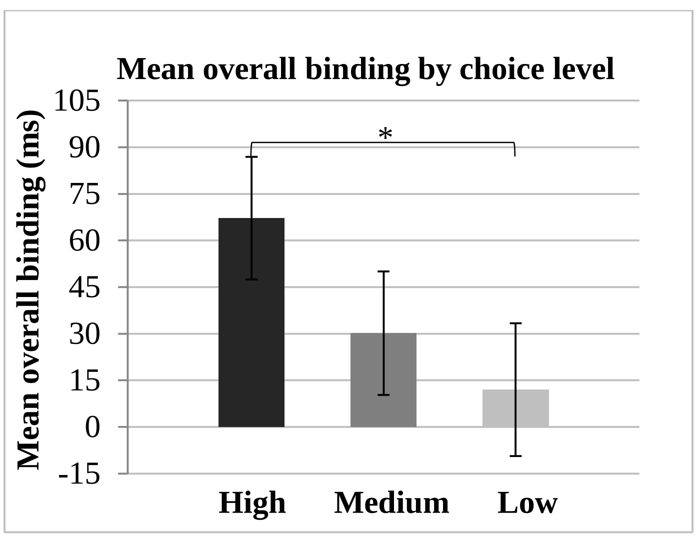

Figure 2.3 Mean overall binding as a function of action choice. Error bars represent SEM (*$p<.05$).

2.5 Discussion

Previous research focusing on different forms of the SoA has examined the contribution of various factors including predictive and retrospective processes (see Moore & Obhi, 2012 for a full review of these studies). Action selection is a crucial aspect of the agentic experience and has been shown to enhance the explicit feeling of control when facilitated by the subliminal priming of action alternatives (Wenke et al., 2010). The goal of the present study was to examine how intentional binding would be influenced by different levels of action choice. This is an important question given popular notions about how freedom and agency are intertwined (e.g., Pettit, 2001).

We measured the perceived times of individual key press and tone events separately in both baseline and operant conditions which allowed us to compare the size of the perceptual shift between each level of action choice. First, we found that perceived times of key presses for all levels of choices were shifted forward in time. In the medium level and high level conditions, the direction of the perceived time of the tones was shifted toward the key press whereas, somewhat surprisingly, this was not the case for the no-choice condition. Importantly though, as Figure 2.2 shows, the overall shift for each individual event (i.e. key press and tone) were in the expected direction and demonstrate the intentional binding effect. Of more interest, we found that the degree of overall binding was greatest when participants had the highest level of action alternatives to choose from. In the medium choice condition, binding was not significantly different from the no choice condition, but both these conditions displayed less binding than the high choice condition. Moreover, the magnitude of the binding in three conditions displayed a parametric trend increasing from none to three and seven alternatives (see

Figure 2.3). Thus, these results provide support for the notion that a high degree of choice is associated with greater action-effect binding than lower degrees of choice. These results serve to connect the SoA to free-choice and are also consistent with the common societal notion that the exercise of personal choice, freedom and agency are intimately intertwined (Hirschmann, 2003; Krause, 2012).

What could be driving our observed effects of choice on intentional binding and by extension, the SoA? Given that all possible actions in the set of alternatives produced the same auditory event, our method could be construed as a true test of action selection on the SoA. That is, there is no obvious reason why an individual participant may have chosen one action over another, given that the outcome, or reward value of each possible action was fixed. Several explanations are possible.

First, the results we report here are consistent with the finding that intentional binding is stronger when participants specify both the *what* and the *when* component of a pending action, compared to when they specify just one of these dimensions (i.e. “when” or “what” - (Brass & Haggard, 2008; Wenke et al., 2009). Participants in the present study were always responsible for specifying the *when* component, but had varying levels of choice about *what* action to make. Specifically, participants were constrained to just one possible action (no choice condition), three possible actions (medium choice condition) or seven possible actions (high choice condition). Thus, in the no choice condition, the action is completely specified externally by the experimenter whereas in both the medium and high choice conditions, the participant must internally specify which action they will ultimately select. By some accounts, the no choice condition can be thought of as more externally triggered than the medium and high choice conditions (see Obhi & Haggard, 2004; Obhi, 2012; Schüür & Haggard, 2011). Correspondingly, it has been shown that activation in areas associated with voluntary preparation to act, such as the supplementary motor area (SMA) is greater for actions that are more internally specified than externally specified (Jahanshahi et al., 1995). Thus one broad explanation for our findings is that more internal, endogenous processing prior to action production is linked to higher levels of agency experience, which manifests as greater intentional binding.

Another interesting framework within which to consider the results of the present study is based on the affordance competition hypothesis that models behaviour as resulting from competition between different representations of potential actions (Cisek, 2007). In this model, action representations are thought of as distributed neural populations that are activated via selective attentional mechanisms (Tipper, Lortie, & Baylis, 1992). By such a view, the action that is finally selected and executed is chosen based on a dynamic reciprocal process operating largely within fronto-parietal circuits which involves mutual inhibition between potential action representations and is subject to biasing by excitatory inputs, some of which arise from cognitive decision making processes (see Cisek, 2007 for a detailed discussion).

Within this framework, we suggest that high, medium, and no choice conditions differ in the degree of this dynamic activation and inhibition process that is ultimately responsible for action selection. Specifically, the no-choice condition may not involve the same degree of this dynamic inhibitory and excitatory activity as the high choice condition. We suggest that this difference might result in stronger activation of the representation of the action selected among many, such as in the high choice condition of the present experiment.

This is akin to more endogenous processing being linked to greater agency, as suggested above, with the endogenous activity being specifically the dynamic interplay between excitatory and inhibitory processes during action selection. This explanation also predicts greater binding for the medium choice condition compared to the no choice condition as reported in our study, although the difference was not significant. From the present study, it appears that when seven alternative actions are available, this is sufficient to change the subjective experience of actions compared to when there is no alternative. However, three alternatives demonstrate no difference from seven or no alternatives. Clearly, more work is required to determine if this suggestion is tenable, but at the very least, our data do indicate that high choice affects binding in a way that no choice does not.

One might argue that the cognitive load varied across three levels of action choices in our study, which could have contaminated our results. However, as previous studies discussed this concern in detail (e.g. Haggard et al., 2002), the errors in time judgments in the operant condition are subtracted from their corresponding baseline conditions (e.g. high level of choice action judgment errors in the baseline condition are subtracted from high level of choice action judgment errors in the operant condition) to calculate the perceptual shifts for each event and condition. Since the potential effect of either cognitive or attentional requirements varying across different levels of choice should be present in both baseline and operant conditions, this effect would diminish as a result of the subtraction we used to obtain the perceptual shifts. We thus feel confident in ruling out the effect of differential cognitive load across conditions.

Having demonstrated that a high degree of choice is linked to increased binding, it is important to consider that there are limitations to the present study. For example, we did not assess the explicit SoA in this study and so cannot speak to how the number of action choice alternatives might affect the explicit feeling of agency. In addition, we did not manipulate the outcome of the different action alternatives. This is an obvious extension of the current work (see Chapter 4 and Chapter 5) and would allow for determining the influence of reward on intentional binding and the SoA.

Despite these limitations, showing that intentional binding is influenced by the degree of action choice is an important finding and we believe the current study provides a new set of questions relating to how choice affects the SoA, which could apply to many domains that extend beyond a fundamental consideration of how the SoA arises.

Finally, the current results bolster the notion that intentional binding is linked, in some complex way to agentic experience. It has previously been shown that priming low power reduces binding and activating memories of depression reduces binding (Obhi et al., 2013), whereas less versus more control of an aircraft, when control is shared with an automatic pilot, reduces binding (Berberian, Sarrazin, Le Blaye, & Haggard, 2012). Given that these scenarios are all accompanied by real changes in the degree of control that an individual either perceives themselves as having, or actually has, the idea that binding and agency are linked is strengthened. The key is for future work to understand *why and precisely how* the SoA and binding are affected by these kinds of manipulations.

For now though, the current results reinforce the suggestion that increased personal choice increases agency which could form the foundation for a sense of freedom.

In the following chapter, we turn our attention to the influence of the valence (i.e., pleasant vs. unpleasant) of action-outcomes on the SoA. After we examine how outcome pleasantness per se can influence the SoA in Chapter 3, we return back to the freedom and choice-level aspects of action selection and their link to the SoA. In Chapters 4-5, we advance the current design of study in such a way that free versus instructed actions (Chapter 4) or dynamically varying types of actions in different choice-levels (Chapter 5) can produce pleasant and unpleasant outcomes.

Chapter 3

Experiment 2: Cultural Background Influences Implicit but not Explicit Sense of Agency for the Production of Musical Tones

Contents

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3.1 Abstract

The sense of agency (SoA) is suggested to occur at both low and high levels by the involvement of sensorimotor processes and the contribution of retrospective inferences based on contextual cues. In the current study, we recruited western and non-western participants and examined the effect of pleasantness of action outcomes on both feeling of control (FoC) ratings and intentional binding which refers to the perceived compression of the temporal delay between actions and outcomes. We found that both western and non-western groups showed greater FoC ratings for the consonant (pleasant) compared to dissonant (unpleasant) outcomes. The intentional binding effect, on the other hand, was stronger for the consonant compared to dissonant outcomes in the western group only. We discuss the results in relation to how cultural background might differentially influence the effect of outcome pleasantness on low and high levels of the SoA.

3.2 Introduction

In the previous chapter, we examined the effect of having a varying number of action alternatives on intentional binding. One of several other questions regarding agentic experience concerns situations where actions generate outcomes that differ in their valence or reward value. Indeed, most human actions are goal-directed and inextricably linked to the outcomes they produce (Elsner & Hommel, 2001; Elsner et al., 2002; Haggard, 2008; Herwig, Prinz, & Waszak, 2007).

Previous research has examined how the reward value of action-outcomes can influence adaptive behavior and cognition in action control (e.g., Aarts, Custers, & Marien, 2008; Marien, Aarts, & Custers, 2012, 2013). This line of research has suggested that the reward signals related to the action-outcomes can increase the motivation and facilitate adaptive control of actions. Aarts et al. (2008), for example, showed that subliminally priming participants with words representing exertion paired with positive words increased the amount of effort displayed during squeezing a hand grip compared to priming with only exertion or positive words. These results suggested that positive primes could have acted as reward signals and thus enhanced the motivation to exert more effort in squeezing the hand grip.

An intriguing question that results from these findings is whether and how the reward or positive value of action-outcomes would affect the subjective experience surrounding actions and the SoA. Previous studies in this vein have shown that negative action outcomes (e.g. vocalization of fear) had an attenuating effect on intentional binding compared to positive (e.g., vocalization of amusement) or neutral (a pure tone) outcomes (Yoshie & Haggard, 2013) and positive monetary gains enhanced the binding effect (Takahata et al., 2012). Also, priming participants with positive pictures compared to neutral ones was found to increase the intentional binding effect (Aarts et al., 2012). In their study, Aarts et al. (2012) presented neutral or positive pictures at the beginning of each trial and measured intentional binding using the clock paradigm (Haggard et al., 2002) and also the eye-blink rate (EBR) of the participants. The reason to include the EBR measurement in their design was to investigate whether potential influence of positive primes on binding could be mediated by EBR, which indirectly reflects the functioning of the dopaminergic system. Notably, previous studies showed that EBR was positively correlated with the concentration of dopamine (e.g., Taylor et al., 1999). Other studies have shown that dopamine agonists and antagonists had increasing and decreasing effects, respectively, on the EBR (e.g., Lawrence & Redmond, 1991). Moreover, dopaminergic system has long been known to involve in the processing of rewards (for a review see Ikemoto, Yang, & Tan, 2015) and in association of actions with their outcomes (Schultz, 2002). Given these findings regarding the link between dopamine and reward processing, action-outcome association, and EBR, Aarts et al. (2012) could examine if the potential effect of positive primes on binding could be explained by changes in EBR. Accordingly, their results showed that binding was stronger with positive than neutral primes. More interestingly, this effect was found to be moderated by individual differences in EBR. That is the difference in binding between positive and neutral primes was greater in individuals with higher spontaneous EBR compared to those with lower. Overall, these results suggested that the influence of positive valence on the SoA, as indexed by intentional binding, was mediated by the dopaminergic system.

From the perspective of social psychology, the abovementioned findings indicating stronger binding with positive or rewarding outcomes can be interpreted with the notion of self-serving bias. Self-serving bias refers to that the tendency to attribute the self as the cause of outcomes is stronger for positive compared to negative or undesirable events (Duval & Silvia, 2002; Miller & Ross, 1975; Taylor & Brown, 1994). It has been argued, however, that there might be cultural differences in this bias. A recent meta-analysis of the relevant research examining cross-cultural differences in self-serving bias suggested that the self serving bias is stronger in U.S. and western than Asian samples (Mezulis, Abramson, Hyde, & Hankin, 2004).

A critical extension to the abovementioned studies examining the relationship between the valence of action-outcomes and the SoA is whether perceived pleasantness can affect the SoA differentially based on potential cultural variations. Thus, in the present chapter we examined how intentional binding and the explicit FoC over action outcomes would be influenced when these outcomes differed in terms of their perceived pleasantness, which is potentially shaped by cultural differences.

As action outcomes, we used consonant and dissonant piano chords that have long been subject to the study by researchers interested in music perception due to the different sensations they evoke in listeners. According to the Pythagorian view, the relative simplicity of the frequency ratio of two tones played simultaneously determines the pleasantness of the outcome sound (Helmholtz, 1877; Tenney, 1988). Consonance, in this regard, refers to the pleasantness produced by the co-occurrence of two tones whereas dissonance is described as unpleasant due to the beating and roughness (Dell'Acqua, Sessa, Jolicoeur, & Robitaille, 2006; Dellacherie, Roy, Hugueville, Peretz,

& Samson, 2011; Plantinga & Trehub, 2013; Shapira Lots & Stone, 2008). The major view regarding the perception of these tonal structures suggests that stability and pleasant-sounding attributes make consonance preferred over instable and rough-sounding dissonance (Bidelman, Krishnan, & Bidelman, Gavin M.; Krishnan, 2009; McDermott & Hauser, 2004).

However, the issue regarding the relationship between psychological and neurophysiological basis of consonance preference and its universal prevalence remains unresolved. One contention is that preference for consonance is innate and is due to certain constraints in the auditory system (Schellenberg & Trehub, 1996a; Tramo, Cariani, Delgutte, & Braida, 2001). In support of this view, studies with infants measuring their looking-time preference suggests that infants as young as 2 and 4-month-olds (Trainor, Tsang, & Cheung, 2002) and 2-day-olds (Masataka, 2006) prefer to listen to consonant excerpts over dissonant ones. However, there is also accumulating evidence suggesting that consonant preference is the product of learning mechanisms. Vassilakis (2005), for example, examined Middle Eastern, North Indian, and Bosnian musical structures and noted that beats, which are thought to reside in dissonance, are well accepted in the musical structure of these cultures. In addition, Plantinga and Trehub (2013) tested consonance preference among 6-year-old infants and found that the listening time to the consonant chords was not longer than dissonant ones. Moreover, they showed that after a 3-minute exposure to either consonant or dissonant stimuli, infants listened to the familiar intervals longer, regardless of their consonant or dissonant status.

The current study takes into account both lines of findings suggesting enhanced SoA over positive outcomes and cultural variances in the perceived pleasantness of consonance to address two important questions. First, these two types of stimuli would allow us to investigate whether low and high levels of the SoA are similarly affected by the pleasantness of action outcomes. Second, as consonance preference is suggested to vary across different cultures (e.g. Vassilakis, 2005), our design could reveal whether this variance can manifest itself on either low or high levels of the SoA.

In the current study, participants completed a computer based task in which they made a voluntary right or left key press which was followed by either consonant or dissonant piano chords. We determined the intentional binding effect, subjective feelings of control (FoC) over the chords, and participants' ratings for how much they liked each of consonant and dissonant chords.

Based on the common bias towards attribution of the self as a cause of positive outcomes (Campbell & Sedikides, 1999), we predicted that the perceived pleasantness of consonant chords would produce higher FoC and liking ratings as well as stronger binding effect (Yoshie & Haggard, 2013) compared to the dissonant ones. As consonant and dissonant chords are based specifically on western tonal structure, our second prediction was that we would observe a greater effect of consonance in the western group compared to the non-western group.

3.3 Method

3.3.1 Participants

In total, 34 right-handed participants were recruited from the participant pool of Wilfrid Laurier University. The study was approved by the Research Ethics Board of

Wilfrid Laurier University, and all participants gave written informed consent prior to beginning the study. We excluded four participants who, in at least one condition, had their mean judgment errors two standard deviations away from the sample mean. In addition, the data of one participant who could not follow the instructions were excluded from the analyses. Inclusion of these participants' data was not found to affect the results reported below.

We divided the remaining 29 participants into two groups based on the post-experimental questionnaire that gathered information about their cultural background. In this questionnaire, they indicated their country of origin and for how long they have been living in Canada. Additionally, they rated on two 10-point scales to indicate their lifetime level of exposure to and preference for western and non-western (i.e., Asian, African, and Middle East) music. For each participant, we calculated the index of exposure to western music by dividing the exposure rating for western music by the sum of ratings for western and non-western music. Similarly, we calculated the index of preference for western music over non-western music to examine the differences between the two groups (see Results).

The western group included 17 participants (6 male, M_{age} = 21.5, *SD*= 5.2) who were born and raised in Canada, USA, or Western Europe. The non-western group consisted of 12 participants (5 male, M_{age} = 21.2, SD = 1.66) who were born in one of the non-western countries listed in Table 3.1. All participants had normal or corrected-to-normal vision and had no hearing problems. 23 of the participants received 11 CAD while the remaining group was granted with 1 course credit in return to their participation.

Table 3.1 Demographic information for the western and non-western group.

Group	Age	Exposure rate for Western music	Preference rate for Western music	Number of years spent in Canada
Western (n=17) *Canada* *USA* *Western Europe*	21.5 (5.2)	.88 (.13)	.66 (.14)	18 (6.7)
Non-Western (n=12) *Bosnia & Herzegovina* *China* *Hong Kong* *Iran* *Malaysia* *Pakistan* *United Arab Emirates*	21.2 (1.66)	.68 (.32)	.53 (.23)	7.6 (4.9)

3.3.2 Apparatus and Procedure

The experiment was programmed in Superlab 4.5 (Cedrus Corporation, USA) and ran on a Dell personal computer (3.07 GHz). Participants sat approximately 50 cm away from a 20 inch monitor (1600x1200) and the responses were recorded on a laptop by the experimenter.

The auditory stimuli consisted of three consonant (perfect fifth, minor third, and perfect fourth) and three dissonant (minor second, major second, and tritone) piano chords and were recorded using Audacity 2.0.3. All of the chords had the same 44.1 KHz sampling rate, 16 bit stereo format, and were 1.5 s in duration. The sound level of the chords was set to 80 dB (See Table 3.2).

Table 3.2 Consonant and dissonant chords used in the study.

Chord	**Frequency Ratio**
Consonants	
Minor Third	6:5
Perfect Fourth	4:3
Perfect Fifth	3:2
Dissonants	
Minor Second	16:15
Major Second	9:8
Tritone	45:32

The first part of the experiment measured the effect of consonance status of the outcomes on intentional binding and consisted of two baseline and two operant conditions. Each of these four conditions was presented in randomly ordered blocks with 72 trials each.

Each trial in the baseline-key press and operant conditions began with the screen indicating the start of a new trial (250 ms) which was followed by the fixation cross presented for 250 ms. The next display prompted the participants to choose either left or right button. Participants were free to choose either the left or the right button at a time of their choosing on a response pad using their right and left index fingers. They were told not to give any stereotyped responses when choosing right or left button and not to press the button at a predetermined time.

The first key press then brought up the screen with a Libet clock on which the clock hand remained stationary for 500 ms and then started its rotation. Participants were told to press the same button at their own pace during the rotation. The reason why participants pressed the same key twice before and after rotation was to avoid any potential effect of the clock hand position (i.e. on the right or left half of the clock) biasing the participants' right or left button choice. In the operant conditions, the second key press produced one of the six chords after a delay of 250 ms. For half of the participants, consonant and dissonant chords were produced by left and right button presses, respectively, and this matching was reversed for the remaining participants. In this way, left button press, for example, randomly produced one of the three consonant chords while the right button produced one of the three dissonant chords. The mapping of the key press and chord type was kept constant throughout the experiment for each participant. Depending on the critical event to be reported in a particular operant block, participants then judged the clock hand position (0 to 59) when either they pressed the button or when they first heard the chord (see Figure 3.1 (A)). In the baseline-key press condition the second key press did not produce any chord and participants judged the timing of their key press. The clock hand continued rotating for 2000 to 2500 ms after their verbal response regarding the time judgments and then the next trial began.

In the baseline-outcome condition, each trial began with a warning signal followed by the fixation cross. The clock was then appeared and one of six different chords was randomly presented during the rotation. Participants judged the clock hand position when they first heard the chord. Time judgments were verbally reported and recorded on a laptop by the experimenter.

After the intentional binding session was completed, participants performed another block of 72 trials to report their FoC over the chords (see Figure 3.1 (B)). Each trial in this block began with the message indicating the trial initiation (250 ms) followed by the fixation cross (250 ms). The next screen prompted the participants to freely choose one of the two buttons as in the intentional binding blocks. Their key press produced one of the six chords after a 250 ms delay and participants rated their FoC over the chord on a 10-point scale (1: not at all, 10: full control).

In the last part of the experiment, participants passively heard each chord and rated on a 10-point scale to indicate how much they liked it (1: not at all, 10: very much). This block consisted of 18 trials in which all six chords were equally presented in a randomized order (see Figure 3.1 (C)). In total thus, participants completed five blocks with 72 trials each and one block with 18 trials throughout the experiment.

After the experimental blocks, participants completed a demographic questionnaire which included items to note their origin of country, weekly amount of exposure to western and non-western music as well as their preference for each. Finally, they were debriefed and thanked for their participation.

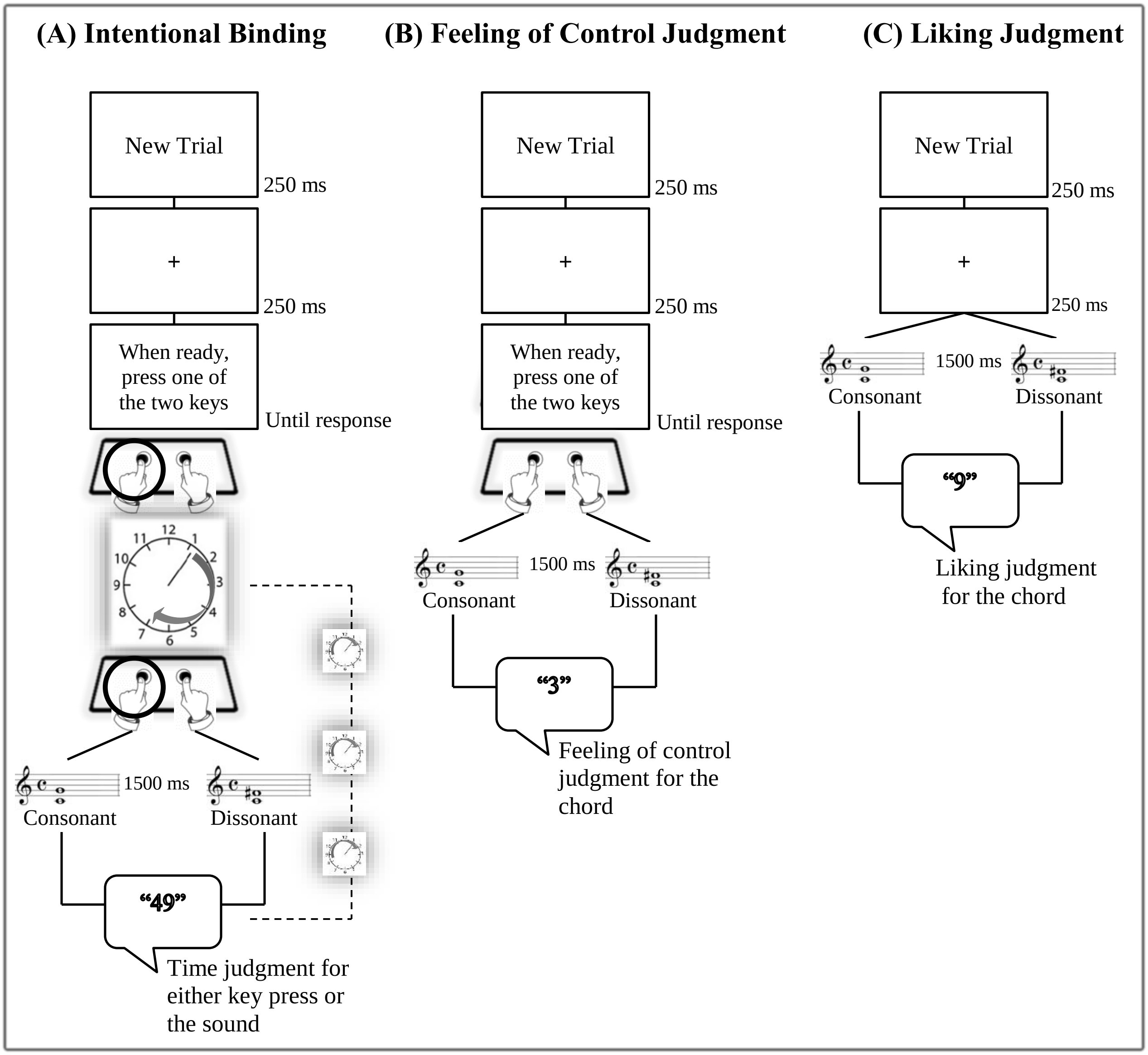


Figure 3.1 Illustration of a sample trial in the operant condition in the intentional binding (A), subjective FoC judgment (B), and liking judgment (C) sessions.

3.4 Results

We excluded the trials with key press response times (RT) shorter than 600 ms and with time judgment errors being three standard deviations away from participant's average judgment error. In addition, trials in which participants made the second key press during the clock rotation different than the one on the previous step were removed from the data. The exclusion criteria resulted in the removal of 3.4 % of all trials (range: 0.7-7.5%).

3.4.1 Musical Exposure and Preference

We first compared the two groups in terms of their exposure to and preference for western music. Independent samples t test revealed that the exposure score was significantly higher in western (*M*=.87, *SD*=.13, N=17) than in non-western (*M*=.68, *SD*=.32, *N*=12) group, *t*(27)=2.17, *p*=.039, two-tailed. Similarly, the western group's ratings score for preferring western music (*M*=.69, *SD*=.14, *N*=17) was significantly higher than that of the non-western group (*M*=.53, *SD*=.23, *N*=12), t(27)=2.23, *p*=.034, two-tailed.

3.4.2 Button Choice

We first examined whether the mapping between right/left button and consonant/dissonant outcome biased participants' choice of key press. For each participant, we calculated the proportion of choosing right versus left button as well as the proportion of choosing the button that produced consonant chords. Paired samples t test revealed that participants chose the right button more often than the left one (*M*=52.80, *t*(28)= 3.19, *p*=.004). Although the ratio of choosing the button that produced consonant chords was higher than that produced dissonance (*M*= 50.40), the difference was not significant (*p*>.05).

3.4.3 Intentional Binding

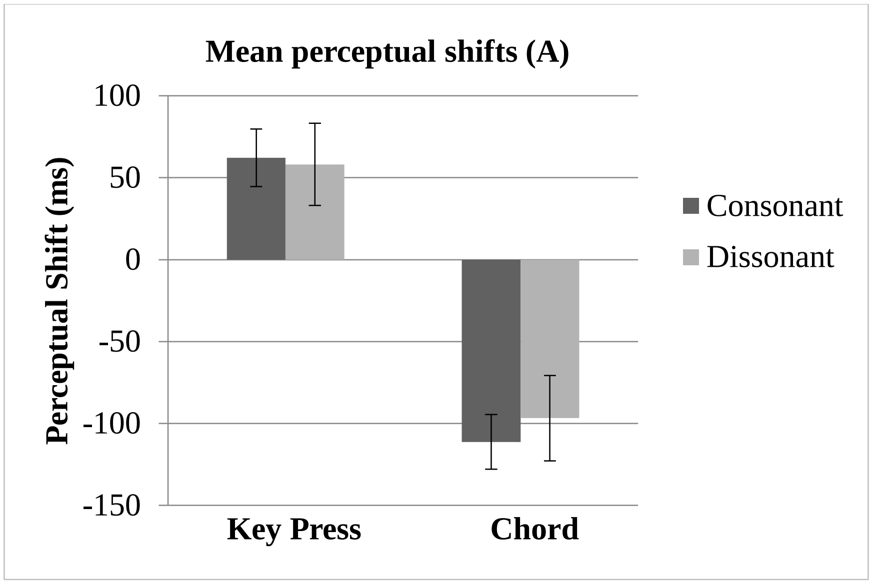
In order to analyze the effect of consonance versus dissonance of action outcomes on intentional binding, we first obtained the perceptual shifts as the difference in the judgment errors between operant and the corresponding single event baseline conditions for both key press and chord judgments (see Table 3.3). Accordingly, the perceptual shifts for the key presses which produced consonant/dissonant chords were calculated as the difference between the judgment errors in the operant-consonant/dissonant (key press judgment) condition and the baseline (key press only) condition. Similarly, the perceptual shifts for the onset of the chord judgments were calculated as the difference between the judgment errors in the operant-consonant/dissonant (chord judgment) condition and baseline (chord only) condition. The positive shifts in the key press judgments and the negative shifts in the tone judgments relative to the corresponding baseline conditions demonstrate the temporal attraction, i.e. the intentional binding effect, between actions and outcomes (Haggard et al., 2002).

Table 3.3 Mean judgment errors in each condition (C and D refers to consonant and dissonant, respectively. For the key presses, they refer to the associated the chord type).

Condition	**Error (SD)**	
	Western	*Non-Western*
Baseline		
Key Press (C)	-30.72 (33.78)	-42.61 (48.96)
Key Press (D)	-27.87 (33.20)	-42.10 (44.08)
Chord (C)	-13.43 (35.36)	-38.41 (58.18)
Chord (D)	-26.19 (45.29)	-33.84 (43.66)
Operant		
Key Press (C)	31.49 (68.91)	15.21 (76.50)
Key Press (D)	30.26 (71.12)	15.33 (77.18)
Chord (C)	-124.66 (98.32)	-139.79 (108.96)
Chord (D)	-122.91 (101.59)	-145.89 (110.55)

We first conducted a 2 x 2 x 2 mixed-design, repeated measures ANOVA with chord (consonant, dissonant) and event (key press, chord) as the within subjects factors, and group (western, non-western) as the between subjects factor. The analysis yielded a main effect of event ($F(1,27) = 90.16$, $p<.001$, $\eta^2 = .77$) suggesting that the perceptual shifts in key press and chord judgments were significantly different. Although we did not observe a main effect of chord on the perceptual shifts ($p>.05$), there was a significant three-way interaction between event, chord, and group ($F(1,27) = 6.66$, $p=.016$, $\eta^2 = .20$). In order to examine the three-way interaction, we conducted 2 x 2 repeated measures ANOVA with chord (consonant, dissonant) and event (key press, chord) for each group (see Figure 3.2 (A) & (B)).

For the western group, we found a significant main effect of event ($F(1,16) = 53.04$, $p<.001$, $\eta^2 = .77$) as well as a significant interaction between chord and event ($F(1,27) = 7.23$, $p=.016$, $\eta^2 = .31$). Paired samples t tests revealed that the difference in the perceptual shifts of key press judgments as well as the difference between the chord judgments for consonant and dissonant chords were not significant (all tests, $p>.05$). For the non-western group, the only main effect we observed was of event ($F(1,11) = 39.9$, $p<.001$, $\eta^2 = .78$).



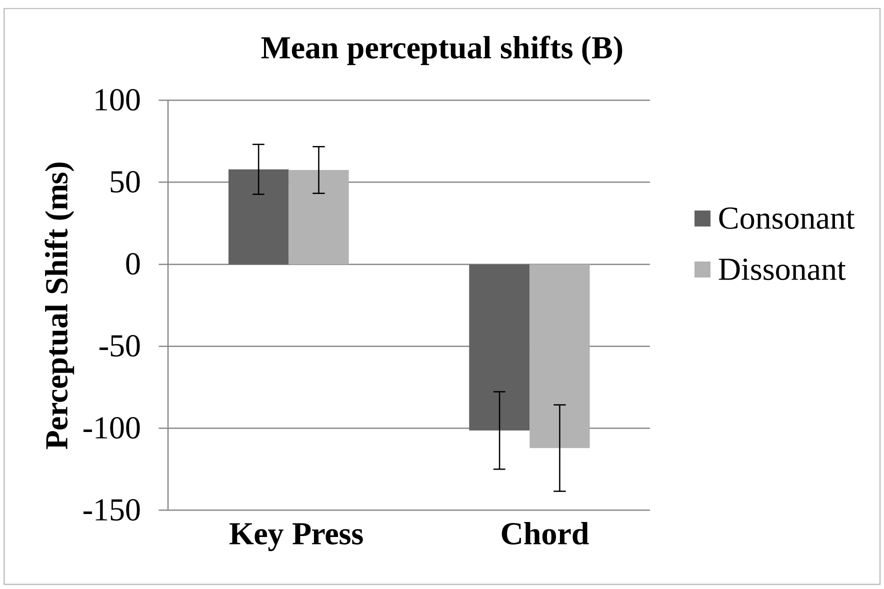


Figure 3.2 Mean perceptual shifts in key press and chord judgments as a function of chord type for the western (A) and non-western (B) groups. Error bars represent SEM.

Second, we calculated the overall binding by subtracting the tone perceptual shifts from the key press perceptual shifts (Wenke, Waszak, & Haggard, 2009). We then conducted a 2 x 2 mixed-design, repeated measures ANOVA with chord (consonant, dissonant) as the within subjects factor and group (western, non-western) as the between subjects factor. The test yielded a significant interaction between chord and group (F(1,27) = 6.66, p =.016, η^2 = .20). We then examined the effect of chord type for each group separately and found that for the western group, the overall binding was significantly greater when the key presses produced consonant chords compared to dissonant ones (F(1,16) = 7.23, p=.016, η^2 = .31). For the non-western group, however, the overall binding did not show difference between consonant and dissonant chords (all tests, p>.05, see Figure 3.3).

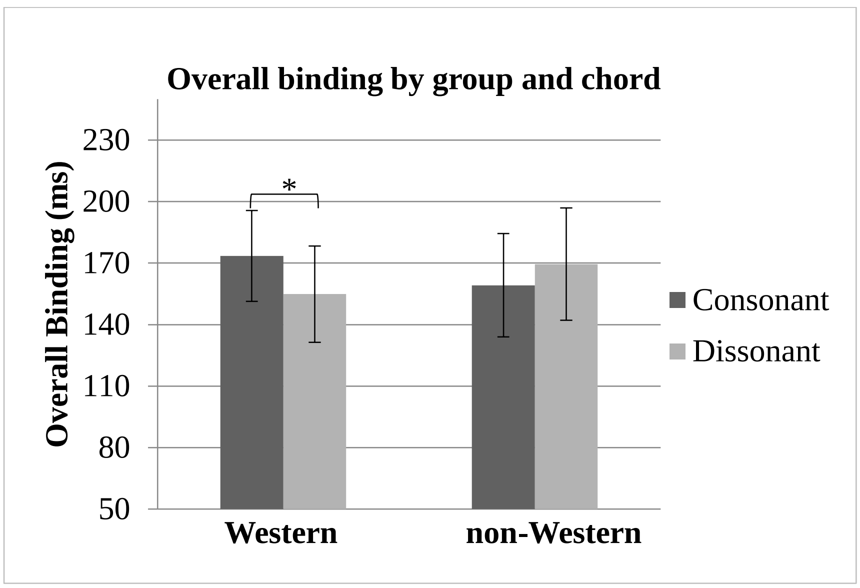


Figure 3.3 Mean overall binding as a function of chord type for both western and non-western groups. Error bars represent SEM (* indicates p<.05).

Finally, we conducted linear regression analyses to explore if the time participants spent in Canada or the level of exposure to western music would predict the overall binding for consonant and dissonant chords. The dependent variables were overall binding for consonant chords and dissonant chords, and the difference in binding between consonant and dissonant chords. Number of years spent in Canada and the ratio of exposure to western music were simultaneously entered as the independent variables. None of the tests revealed any significant relationship between the level of familiarity with western music and intentional binding (all tests, $p>.05$).

3.4.4 FoC Judgments

In order to examine the effect of consonance versus dissonance on FoC judgments, we performed a 2 x 2 mixed-design, repeated measures ANOVA with chord (consonant, dissonant) as the within subjects factor and group (western, non-western) as the between subjects factor. The test revealed a main effect of chord ($F(1,27) = 16.52$, $p<.001$, $\eta^2 = .38$) suggesting that participants felt significantly more in control over the consonant chords than the dissonant chords (see Figure 3.4). The interaction between the chord and group was not significant ($p>.05$).

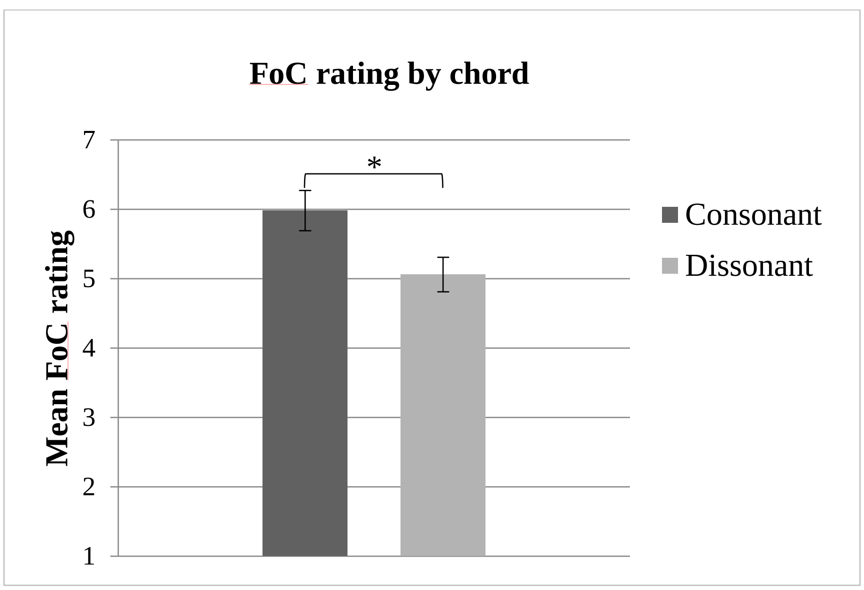


Figure 3.4 Mean FoC ratings across both groups as a function of chord type. Error bars represent SEM (* indicates $p<.05$).

3.4.5 Liking Judgments

A 2 x 2 mixed-design, repeated measures ANOVA with chord (consonant, dissonant) as the within subjects factor and group (western, non-western) as the between subjects factor yielded that participants' liking ratings for consonant chords were significantly higher than dissonant ones ($F(1,27)=63.70$, $p<.001$, $\eta^2 = .70$). There was no interaction between chord and group ($p>.05$). See Figure 3.5.

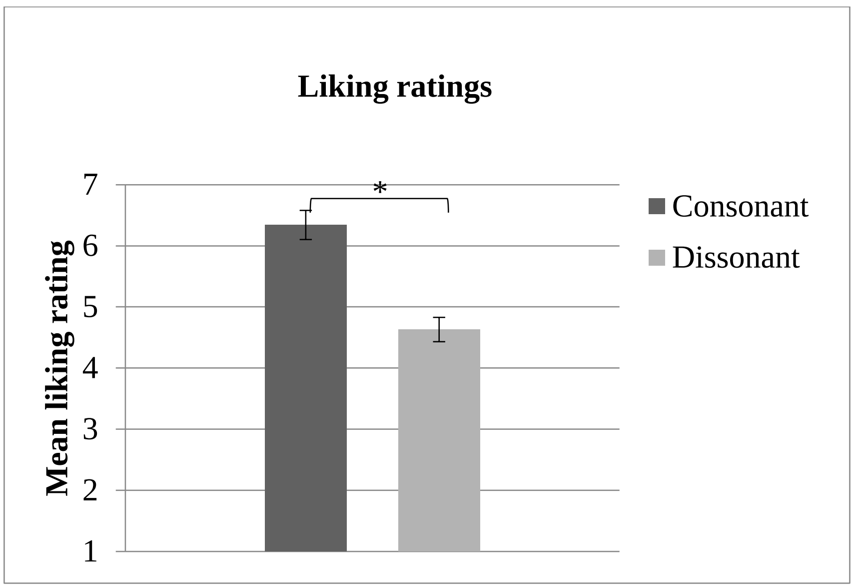


Figure 3.5 Mean liking ratings across both groups as a function of chord type. Error bars represent SEM (* indicates $p<.05$).

Finally, we calculated the difference between consonance and dissonance in overall binding, FoC ratings, and liking ratings. Bivariate correlation analysis showed that the difference score in the subjective control ratings significantly correlated with that in liking ratings (r (27) =.48, $p<.001$).

3.5 Discussion

In the current study, we examined the effect of perceived pleasantness of the action outcomes on both intentional binding and subjective judgments of agency in western and non-western participants. We found that both groups felt significantly more control over the consonant chords than the dissonant ones and gave higher ratings of liking the former than the latter. The low level SoA indexed by the intentional binding effect was influenced by chord type in the western group only. That is, overall binding was significantly greater when western listeners' actions produced consonant rather than dissonant chords whereas non-western listeners showed no differences in the binding effect between the two chord types. Another important result of the current study was that participants' ratings for liking the consonant chords over the dissonant ones correlated with their respective FoC judgments. These results are noteworthy both in terms of consonance preference and cross cultural examination of the SoA at both low and high levels.

Regarding consonance preference, both groups in our study reported liking consonant chords more than dissonant chords. Although the discussion about whether consonance preference is culture dependent or innate is beyond the scope of this paper, our results seem to support the notion of a universal preference for consonance. However, the group of non-western listeners in the current study was not completely isolated from exposure to western music. A cross-cultural comparison including a group with a completely different background of musical experience would provide a more solid ground to investigate this issue. For the moment, however, the explicit liking measure suggests a strong preference for consonance across individuals from various cultures (see also Fritz et al., 2009).

Of more interest are the results regarding the effect of consonance status on the low and high level SoA and the differences between the two groups. Regarding the high level of the SoA as indexed by the FoC ratings in our study, the finding that both groups reported higher FoC over consonant than dissonant chords could strongly be related to the self-serving bias according to which causal attributions to self are stronger for positive than negative action outcomes (e.g., Campbell & Sedikides, 1999). The potential effect of self-serving bias on the FoC judgments becomes more tenable as we consider the finding that both groups reported to have found the consonant chords more pleasant than the dissonant ones. Moreover, this was positively correlated with the FoC ratings. It is thus fair to suggest that the difference we observed in agency judgments for two types of outcomes was driven by the self-serving bias.

A more intriguing aspect of our findings concerns the differential effect of consonance status of action outcomes on intentional binding between two groups. To reiterate, we found that the western group showed greater binding for consonance than dissonance whereas the non-western group did not exhibit such an effect by the chord type. The crucial question here is why the western group showed stronger SoA over more pleasant outcomes at both low and high levels while the non-western group displayed the same effect only at the high level. If self-serving bias was the driving force for stronger agentic experience at the low level, we would expect both groups to display similar results on the intentional binding effect. However, previous studies provide deeper insight into how culture specific variations might influence the self serving bias and self evaluations in general. It has been suggested, for example, that the self serving bias is stronger in western than most of the Asian cultures (Mezulis et al., 2004). More importantly, cross cultural differences in the degree of self-evaluations and self-enhancement were found to be more apparent on implicit measures while explicit measures might not reveal any such difference (Hetts, Sakuma, & Pelham, 1999). Accordingly, Hetts et al. (1999) showed that Eastern immigrants showed conflicting results in associating self relevant prime words with positive or negative target words. That is, while the explicit measure of self-evaluation suggested that Eastern participants tend to associate the self concept more with the positive words just as American participants, response times taken as the implicit measure did show any bias towards self-enhancement in Eastern participants. On the basis of their results, the authors suggested that implicit measures reflect culture specific attitudes more readily than conscious evaluations of the self, which might be vulnerable to situational factors. Regarding our results, it is therefore fair to suggest that non-western participants showed a similar self-serving bias as the western group on the explicit judgments of agency while the two groups diverged in the effect of pleasantness of action outcomes on the low level SoA. In other words, relatively weaker bias of self-enhancement in non-western participants might have yielded no effect of outcome type on their low level SoA.

An alternative explanation of our results concerns the potential difference in the degree of familiarity with consonance versus dissonance. It is possible that, for the western group who are more familiar with consonance than dissonance there is a difference in the quality of predictions produced by the forward model for consonant chords compared to the dissonant chords. Specifically, for the western participants, this difference in the quality of predictions or amount of motor preparation for consonant and dissonant chords might have yielded stronger overall binding between key presses and consonant chords. For the non-western group, on the other hand, the difference in the strength of predictions towards consonance versus dissonance might not be that obvious as they have presumably been exposed to the both in their cultural origin (Vassilakis, 2005).

Taken together, our results suggest that pre-reflective and conscious experience of agency may be differentially affected by the cultural background of participants. This difference in the effects of cultural background on low level and high level agency supports the notion that the two forms of agency may be supported by dissociable neural mechanisms (Moore & Obhi, 2012).

There are certain limitations to the current study that need to be addressed in future research. For example, for westerners we made an assumption that greater exposure to western music would imply a higher level of familiarity with and preference for consonant chords compared to dissonant chords. Similarly, we considered the non-western listeners' reporting lower exposure to western music would bring about milder difference between consonant and dissonant chords. However, although the level of exposure might be a potential cause for the difference in how chord type affected the intentional binding in two groups, we did not find a significant relationship between the level of familiarity with western music and the binding effect. Further research should employ a more precise method to measure the level of exposure to western music by recruiting participants with a wider range of exposure from high to low. Another limitation of our study is that we did not measure our participants' implicit or explicit status of self-serving bias as applied in previous studies which reported a conflict in the implicit and explicit belief systems in Eastern cultures (e.g. Hetts et al., 1999). Future experiments would provide a deeper insight if they employed valid measures of culture specific variations in the mechanism of self-evaluation. Finally, the baseline-chord condition in our study was different from the operant-chord condition in terms the predictability of the chord type and timing. However, we believe it is unlikely for this to contaminate our results as we did not find any effect of chord type on the chord judgment errors in the baseline and operant conditions.

In sum, the current study raises several important ideas concerning the SoA and potential differences across cultures. First, we have shown that the perceived pleasantness of action outcomes influences the subjective judgement of the SoA such that more control is felt over desirable outcomes of actions. Second, the low level SoA indexed by the intentional binding effect can either parallel or not parallel the higher level judgment of agency depending on several possible factors, one of which appears to be cultural background and the level of prior exposure to consonant and dissonant tones. The current study also opens up a relatively new dimension of research concerning cross-cultural differences in the SoA. How culture interacts with the brain to shape an individual's phenomenological experience of their own actions is a fundamental question that we hope will spawn many interesting experiments in years to come.

In the following chapter, the question of interest is how the SoA would be altered when actions are either freely chosen or performed as instructed and when these actions can produce either pleasant or unpleasant outcomes.

Chapter 4

Experiment 3: Effects of Free Action Selection and Pleasantness of Action Outcomes on the Sense of Agency

Contents

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CHAPTER 4

4.1 Abstract

Actions can be freely chosen or instructed and action outcomes can vary in pleasantness. To assess how these factors affect the sense of agency, participants performed freely selected or instructed key presses which could produce pleasant or unpleasant chords. We obtained estimates of the key press-chord intervals and feeling of control ratings (FoC) over the outcomes. Interval estimates were used to index intentional binding - the perceived temporal attraction between actions and their outcomes. Results showed stronger binding and higher FoC ratings in the free compared to instructed condition. Additionally, FoC was stronger for pleasant compared to unpleasant outcomes, and for pleasant outcomes that were produced by freely selected compared to instructed actions. These results highlight the importance of free action selection on the SoA. They also reveal how freedom of action selection and pleasantness of action outcome interact to affect the feeling of control.

4.2 Introduction

The capacity to freely choose one's actions is fundamental to action control (Haggard, 2008; Nichols, 2011). Environmental conditions, however, can impose various factors that modulate one's freedom and self-involvement in action selection. As discussed in Chapter 2, the degree of self-involvement in actions can be varied by how much of the decisions regarding *whether* to act or not, *what* action to perform, and *when* to perform an action (Brass & Haggard, 2008; Haggard, 2008) is self-determined.

In the study presented in Chapter 2, we manipulated the *what* dimension of actions such that the number of action alternatives could be either one, three, or seven. We reported that binding, as an indirect index of the SoA, was strongest when the context provided the highest number of alternatives (i.e., seven). Based on these results, we suggested that one's freedom to choose an action among (relatively) higher number of alternatives would bolster the SoA due to greater endogenous processing in the case of a large choice space. More clearly, selection of an action among high number of alternatives would result in greater activation of the final selection of an action compared to when one has none or few options. To reiterate, this interpretation was based on the affordance competition hypothesis (Cisek, 2007) that accounted for internal processing of action alternatives and suggested that an action is selective through the mechanism of dynamic inhibition and excitation of action representations. We also speculated that predictions produced by forward model (e.g., Blakemore, Wolpert, & Frith, 2002) towards the outcome of the selected action could also be stronger in the high-choice condition, which in turn could have led to greater binding compared to the no-choice condition. This study was the first to manipulate the choice-level in action selection and examine its impact on the SoA.

Earlier research, in a similar vein, manipulated the source of at least one dimension of action decisions (i.e., whether, what, and when) as freely determined or externally instructed while the actions were limited to two alternatives. Wenke, Waszak, and Haggard (2009), for example, varied the timing and the choice of actions such that participants could either freely choose one of two keys or press the instructed key at a time of either their own choice or during a pre-specified interval. Using a similar paradigm to Haggard et al. (2002), participants were instructed to judge the time of either their key press or the resulting tone, in order to determine the size of the intentional binding effect across free and instructed choice conditions. Wenke et al. (2009) found that binding between the perceived times of key presses and tones was greater when both the choice and timing of actions were specified by the same source, (i.e., either freely selected or instructed), compared to when these dimensions were determined by different sources. On the basis of their results, the authors suggested that pronounced binding found in their study was owed to the compatibility of sources determining both the what- and the when-dimensions of actions. In their view, therefore, a conflict between the regarding sources would result in weaker binding.

Another line of research investigated the neural basis of free versus instructed actions and have shown that the contrast between free choice and instructed actions was associated with increased BOLD activity in dorsolateral prefrontal cortex (DLPFC), inferior parietal lobe (IPL), rostral cingulate zone (RCZ), and supplementary motor area (SMA) (Cunnington et al., 2002; Filevich et al., 2013; Waszak et al., 2005). In an earlier study, the time of actions (i.e., extension of a finger) could be either self-initiated or externally triggered by the onset of auditory stimulus (Jahanshahi et al., 1995) and a PET (Positron Emission Tomography) scanning procedure was employed to measure the brain activity and the changes in movement related cortical potentials. Their results showed that self-initiated movements were associated with a specific network of brain areas including DLPFC, SMA, anterior cingulate, insular cortex, the lateral PMC, parietal area 40, the thalamus, and the putamen. Moreover, the peak amplitude of a movement related cortical potential, namely the readiness potential (RP), was greater in self-initiated compared to externally triggered movements.

In another study, similarly, Obhi and Haggard (2004) assessed electromyographic (EMG) activity (reflecting the preparation of the muscles) in the right first dorsal interosseous while the onset time of participants' finger press actions could be either self-initiated or triggered by a tactile stimulus. The results showed that the EMG activity prior to action execution was greater when actions were self-initiated compared to when they were externally triggered. These results landed further support to the physical differences between self-initiated and externally triggered actions.

Although the studies mentioned above, including the study in Chapter 2, attempted to understand the differences between free versus instructed actions on the basis of the underlying neural structures and the phenomenology of actions, questions remain whether these differences could also be salient depending on the value of action-outcomes. As noted in Chapter 3, most human actions are goal-directed and related to the outcomes they produce (Elsner & Hommel, 2001; Elsner et al., 2002; Haggard, 2008; Herwig et al., 2007). In this regard, the reward or positive value of action-outcomes has been shown to enhance the motivational behaviour in actions (e.g., Aarts, Custers, & Marien, 2008) and also enhance the SoA indexed by intentional binding (Aarts et al., 2012; Takahata et al., 2012).

In order to extend this line of research concerning the valence of outcomes, in Chapter 3, we examined the influence of pleasantness of outcome tones on both intentional binding and FoC ratings. Specifically, we used consonant and dissonant piano chords as outcome sounds that are- according to several physiological and psychological accounts of music perception- regarded as pleasant versus unpleasant, respectively (Dell'Acqua, Sessa, Jolicoeur, & Robitaille, 2006; Dellacherie, Roy, Hugueville, Peretz, & Samson, 2011; Helmholtz, 1877; Plantinga & Trehub, 2013; Shapira Lots & Stone, 2008; Tenney, 1988; Bidelman & Krishnan, 2009; McDermott & Hauser, 2004; Schellenberg & Trehub, 2013; Tramo, Cariani, Delgutte, & Braida, 2001). To reiterate, the study of Chapter 3 assessed both FoC judgments and intentional binding while participants' right or left key presses could produce either pleasant or unpleasant outcomes. We found that the amount of binding (in the western group only) and the subjective FoC over the chords was stronger when the outcome chords were pleasant compared to when they were unpleasant. These results supported the notion that positive or desired outcomes tend to be perceived as more strongly self-caused compared to negative, relatively undesirable outcomes. Moreover, this study promoted the investigation of cross-cultural differences in how agency (particularly at the low level) can be shaped by the valence of action-outcomes.

To summarize, abovementioned findings demonstrate (i) activation differences in the brain between self-generated versus externally triggered actions (Cunnington et al., 2002; Filevich et al., 2013; Forstmann et al., 2008, 2006; Jahanshahi et al., 1995; Waszak et al., 2005), (ii) the influence of source compatibility between the what and when dimension of action on binding (Wenke et al., 2009), (iii) stronger binding with high number of action alternatives (Chapter 2), and (iv) greater binding and FoC with pleasant compared to unpleasant outcomes (Chapter 3). One question, at this point, is to further probe how the SoA would be affected when the context includes both the manipulation of the source of action selection (free vs. instructed) and the valence of action-outcomes (pleasant vs. unpleasant).

The goal of the present chapter is to address this question. Accordingly, participants performed either self-selected (free-choice) or externally specified (instructed) key presses that could randomly produce either a pleasant or an unpleasant chord. In the free-choice condition, participants could choose a key among four alternatives while in the instructed-choice condition, the selection was based on an instruction stimulus indicating which of the four keys to press. Between participants, we obtained estimations of the temporal interval between key presses and chords and FoC ratings over the chords. Based on the findings presented in Chapters 2-3, we expected stronger binding and higher FoC ratings in the free-choice than instructed-choice condition and when the outcome chords were pleasant than when they were unpleasant.

4.3 Method

4.3.1 Participants

In total, we recruited 46 undergraduate students from Wilfrid Laurier University. Participants were randomly assigned to either the interval estimation or the FoC rating task condition. Accordingly, 23 participants completed the interval estimation task (5 male, 2 left-handed, M_{age} = 18.87, *SD*= 1.10) while the remaining 23 participants completed the FoC rating task (8 male, 5 left-handed, M_{age} = 19.17, *SD*= 1.77). 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. Participants were compensated with course credits in exchange for their time.

4.3.2 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: 1600x1200). Presentation of all stimuli was centered on a white background. Responses were made on a 5-key response pad. On this pad, four keys were placed on the right, left, up, and down side of the central key. An optical wheel mouse was used to indicate responses on visual analogue scales presented on the screen for interval estimation, FoC rating, and pleasantness rating tasks. The interval estimation scale was ranged from 1 to 1000 ms and marked at 50 ms intervals. FoC and pleasantness rating scales were marked at 0.5 point intervals from 1 to 6.

Auditory stimuli consisted of two consonant (perfect fifth and perfect fourth) and two dissonant (minor second, major second) piano chords. These chords were recorded using Audacity 2.0.3, sampled at 44.1 kHz with a 16 bit stereo format. Each chord was 1 s in duration and was presented at 60 dB through the headphones.

4.3.3 Procedure

A schematic of the tasks and the procedure is given in Figure 4.1. For each task of interval estimation and FoC rating, participants were first familiarized with the tasks and the stimuli, and completed 10 practice trials. Practice session was repeated only once for the participants who had difficulty in understanding the task and who made any errors in instructed-choice trials. Each task consisted of 288 trials in total, which were presented in a random order within 6 mixed blocks of 48 trials each. After completing each block, the experiment paused to allow participants to take a break, and continued after the experimental instructions for each task were presented on the screen.

Each trial began with a 1 s presentation of an image representing the central key on the response pad. Participants were instructed to rest their left index finger on the central key when this image was presented. The following screen displayed one of five images representing either a specific key (right, left, up, down) or all four keys placed around the central key (see Figure 4.1). In the instructed-choice condition, only one specific key was presented and participants were required to press that exact key. In the free-choice condition, all four keys were presented and participants were free to choose any of the four keys. Participants were instructed to respond as fast as possible to the target stimulus and avoid giving stereotyped responses in the free-choice condition. The target stimulus remained on the screen until one of four keys was pressed. In case of an erroneous key press in the instructed-choice condition, a cross sign appeared on the screen and the trial ended. A valid response was followed by one of three delays (100 ms, 300 ms, 500 ms) before one of four auditory stimuli (1 s in duration) was presented. In the interval estimation task, participants were told that keypress-chord intervals would randomly vary between 1 and 1000 ms. After the chord was presented, the interval estimation scale was presented on the screen and participants were to indicate their estimation of the delay using the mouse with their right hand. No prior training was given for interval estimations and participants were told to rely merely on their sense of time when performing the interval estimations. In the FoC rating task, instead, the chord was followed by a 6-point visual analogue scale (1: the lowest level of control; 6: the highest level of control) participants were required to indicate the degree of control they felt over the production of the chord. They were told not to base their judgments on how fast or accurately they responded when making the key presses. Participants again used the mouse with their right hand and moved the cursor to any point on the scale and clicked to indicate FoC judgments. Inter-trial interval was set to 500 ms during which a blank screen was presented.

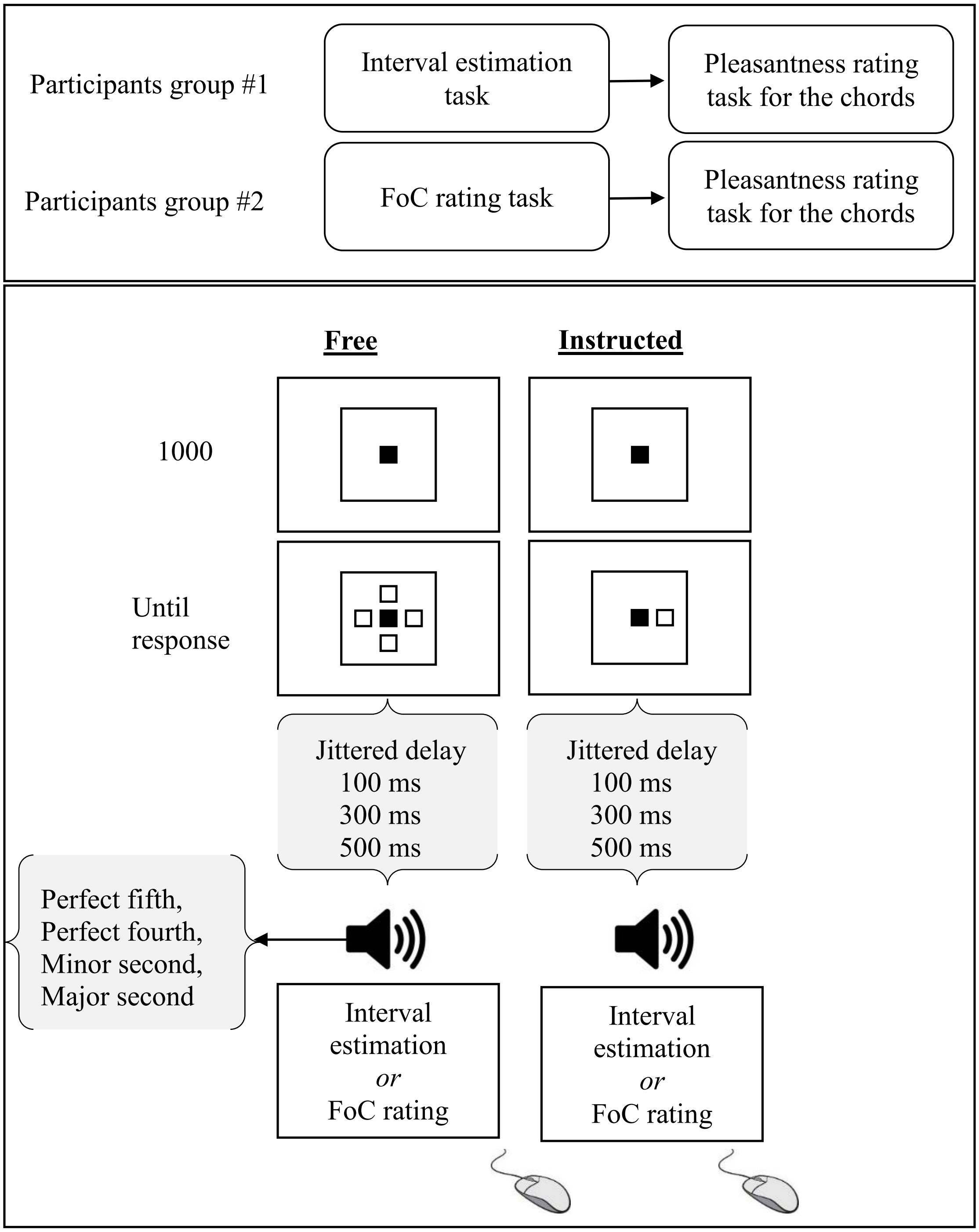


Figure 4.1 Schematic illustration of the tasks completed by each group of participants (upper panel) and the sample trial procedure in the interval estimation and FoC rating tasks (lower panel).

Each group of participants completing either the interval estimation or the FoC rating task finally performed the pleasantness rating task which aimed at measuring the subjective pleasantness of the chords used in the experiment. This task consisted of a block of 20 trials. Each chord was thus presented four times in a random order. The trials began with a 1500 ms presentation of the text message “Listen”. One of four chords was then delivered through the headphones and participants rated on a 6-point scale (1: very unpleasant; 6: very pleasant) to indicate how pleasant they found the chord. A 500 ms interval was placed before the next trial was presented.

At the end of the experiment, participants were debriefed about the goal of the study and thanked for their time.

4.3.4 Data processing

4.3.4.1 *Raw data outlier exclusion*

For the interval estimation task, trials with RTs or interval estimations being three standard deviations away from the mean, or those with incorrect responses (pressing the wrong key in the instructed-choice condition) were excluded ($M_{excluded}$ = 2.18%, *SD*= .64% of all trials). The same criteria (except the interval estimation criterion) were also applied for the FoC rating task data ($M_{excluded}$ = 2.49%, *SD*= .73% of all trials).

4.3.4.2 *Participant exclusion*

The criteria to exclude a participant’s data was having more than 20% of all trials excluded or failing to demonstrate a monotonic increase across the mean estimations of 100 ms, 300 ms, and 500 ms delays. No participant’s data were excluded due to these criteria.

4.3.4.3 *Data analyses*

A repeated measures analysis of variance (ANOVA) was conducted to examine the effects of choice (free, instructed) and valence (pleasant, unpleasant) on interval estimations and FoC ratings. RTs were analyzed as a function of key (right, left, up, down) and choice (free, instructed) while pleasantness ratings were analyzed by factoring in chord (perfect fifth, perfect fourth, minor second, major second). RTs and pleasantness ratings were analyzed combining the data from both interval estimation and FoC rating tasks. Greenhouse-Geisser correction was used where Mauchly's test of sphericity was violated. *Post hoc* multiple comparisons (Bonferroni corrected) were performed where differences across variable levels were examined. Additionally, two-tailed paired samples t-tests and one sample t-tests were conducted where appropriate. All data analyses were conducted using SPSS (version 16.0) and the significance level was set to .05.

4.4 Results

4.4.1 Accuracy

Mean percentages of accuracy in the instructed-choice condition was 99.34% (*SD*=.86) and 99.05% (SD=.98) in the interval estimation and FoC rating tasks, respectively.

4.4.2 Interval estimation

We calculated the mean interval estimations for each level of choice, outcome valence, and delay. Accordingly, estimate data were subjected to a 2 x 2 x 3 repeated measures ANOVA with choice (free, instructed), valence (pleasant, unpleasant), and delay (100 ms, 300 ms, 500 ms) as within subjects factors. The analysis yielded a significant main effect of choice ($F(1,22) = 5.71$, $p=.026$, $\eta^2 = .21$) such that interval estimations were significantly shorter when participants freely chose (*M*=420.59, *SD*=105.75) which key to press than when the key press was instructed (*M*=433.43, *SD*=108.77, see Figure 4.2). The main effect of delay was also significant ($F(2,44) = 133.52$, $p<.001$, $\eta^2 = .86$), indicating that perceived intervals were significantly increased ($p<.001$, at all levels) across 100 ms (*M*=271.63, *SD*=90.50), 300 ms (*M*=428.37, *SD*=99.17), and 500 ms (*M*=581.03, *SD*=132.12). Outcome valence[2] did not have any significant effect or interactions with choice and delay on the perceived intervals (*F*s<1, *p*s>.5). Finally, there was a significant interaction between choice and delay ($F(2,44) = 4.20$, $p=.021$, $\eta^2 = .16$). In order to resolve the interaction, we performed paired samples t tests to compare the choice levels at each delay. Accordingly, the test revealed that perceived intervals at 100 ms were not significantly different between free (*M*=273.52, *SD*=84.99) and instructed (*M*=269.73, *SD*=86.59) conditions; $t(22)= .48$, $p=.633$, two-tailed. At 300 ms, free choices yielded significantly shorter interval estimations (*M*=420.39, *SD*=94.68) compared to the instructed choices (*M*=436.34, *SD*=97.08); $t(22)= -2.22$, $p=.037$, two-tailed. Finally, at 500 ms, perceived intervals in the free condition (*M*=567.85, *SD*=126.84) were significantly shorter than the instructed condition (*M*=594.22, *SD*=129.52); $t(22)= -2.85$, $p=.009$, two-tailed (see Figure 4.3).

[2]Although the number of trials for each condition is rather low (12), we also analyzed the influence of valence on the interval estimations by factoring in the chord type (perfect fifth, perfect fourth, minor second, major second) and yet did not find any significant effects.

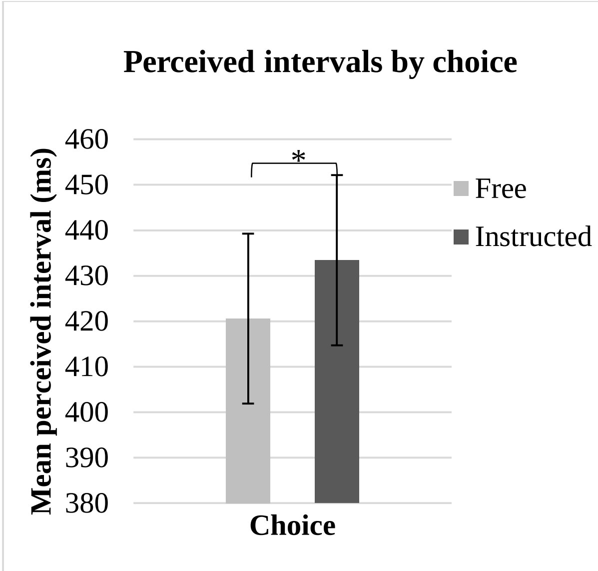


Figure 4.2 Mean perceived intervals in free-choice and instructed choice conditions (* *p*<.05). Error bars represent SEM.

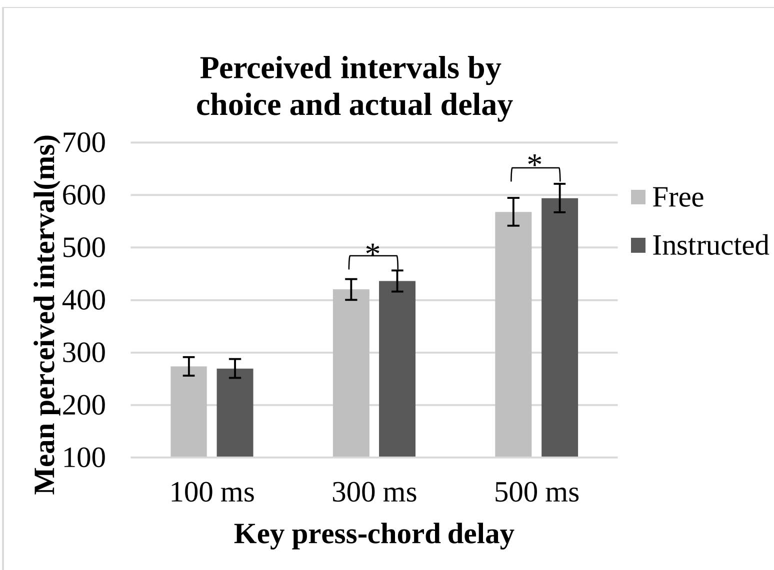


Figure 4.3 Mean perceived intervals as a function of choice (free, instructed) and delay (100 ms, 300 ms, 500 ms) (* *p*<.05). Error bars represent SEM.

4.4.3 FoC ratings

Mean FoC ratings were calculated for each choice type, outcome valence, and delay condition and were subjected to a 2 x 2 x 3 repeated measures ANOVA with choice (free, instructed), valence (pleasant, unpleasant), and delay (100 ms, 300 ms, 500 ms) as within subjects factors. The test revealed significant main effects of choice ($F(1,22) = 8.03$, $p=.010$, $\eta^2 = .27$), valence ($F(1,22) = 28.55$, $p<.001$, $\eta^2 = .56$), delay ($F(2,44) = 9.09$, $p=.002$, $\eta^2 = .29$), and a significant interaction between choice and valence ($F(1,22) = 8.61$, $p=.008$, $\eta^2 = .28$). No other significant effects or interactions were found by the analysis of FoC ratings (All *F*s<1, *p*s>.6).

More specifically, FoC ratings (see Figure 4.4) were significantly higher when choices were freely chosen (*M*=3.96, *SD*=.77) than instructed (*M*=3.79, *SD*=.67) and when outcome chords were pleasant (*M*=4.33, *SD*=.66) than they were unpleasant (*M*=3.43, *SD*=.78). Regarding the main effect of delay, *post hoc* tests showed that FoC ratings were systematically decreased (see Figure 4.5) as the delay increased from 100 ms (*M*=3.99, *SD*=.71), to 300 ms (*M*=3.85, *SD*=.72) and 500 ms (*M*=3.78, *SD*=.73). FoC ratings at 100 ms were significantly higher than both at 300 ms ($p=.006$) and 500 ms ($p=.008$). However, FoC ratings at 300 ms did not significantly differ from that at 500 ms ($p>.4$).

Further analysis of the interaction between choice and valence revealed that FoC ratings were significantly higher over the pleasant outcomes when participants freely chose (*M*=4.46, *SD*=.67) which key to press than it was instructed (*M*=4.19, *SD*=.58); $t(22)= 3.59$, $p=.002$, two-tailed. However, the difference in the FoC ratings between free (*M*=3.46, *SD*=.83) and instructed (*M*=3.39, *SD*=.69) choices for the unpleasant outcomes was not significant; $t(22) = 1.06$, $p = .302$, two-tailed. Finally, for both free ($M_{pleasant} = 4.46$, $SD_{pleasant} = .67$; $M_{unpleasant} = 3.46$, $SD_{unpleasant} = .83$) and instructed choices ($M_{pleasant} = 4.19$, $SD_{pleasant} = .58$; $M_{unpleasant} = 3.39$, $SD_{unpleasant} = .69$) differences in the FoC ratings between pleasant and unpleasant outcomes were significant ($t(22) = 5.28$, $p < .001$; $t(22) = 5.25$, $p < .001$ for free and instructed choices, respectively).

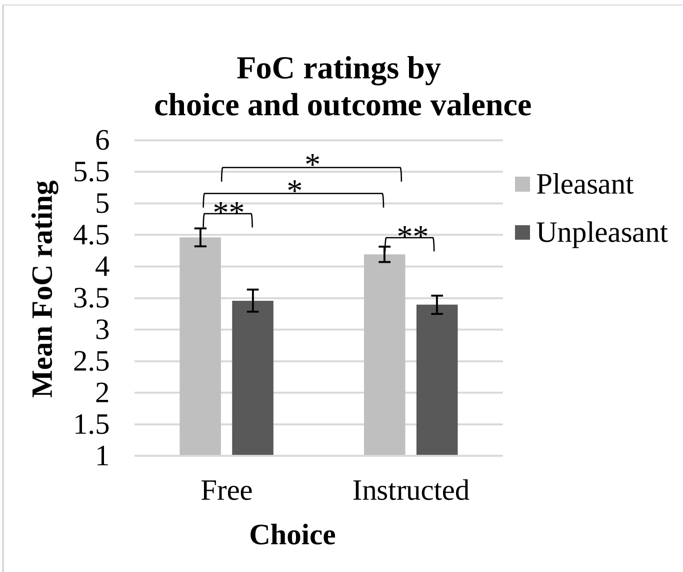


Figure 4.4 Mean FoC ratings as a function of choice (free, instructed) and outcome valence (pleasant, unpleasant) (* $p < .05$, ** $p < .001$). Error bars represent SEM.

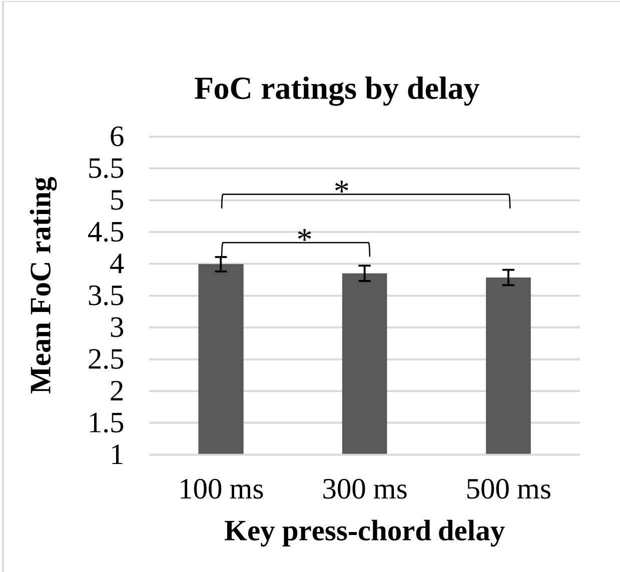


Figure 4.5 Mean FoC ratings as a function of delay (100 ms, 300 ms, 500 ms) (* $p<.05$). Error bars represent SEM.

4.4.4 Response times (RTs)

RTs (see Figures 4.6 & 4.7) were analyzed by a 2 x 4 repeated measures ANOVA with choice (free, instructed) and key (right, left, up, down) as within subjects factor. The test revealed a main effect of choice ($F(1,45) = 22.68$, $p<.001$, $\eta^2 = .33$) such that choices were significantly slower in the free (M=636.32, SD=142.97) than instructed (M=586.71, SD=86.49) condition. The main effect of key was also significant ($F(3,135) = 23.34$, $p<.001$, $\eta^2 = .34$). *Post hoc* tests revealed that pressing right (M=590.64, SD=107.26) and left (M=595.68, SD=107.02) keys were both significantly faster than pressing up (M=635.90, SD=125.85) and down (M=623.85, SD=118.77) keys ($p_{right\text{-}up}<.001$, $p_{right\text{-}down}<.001$, $p_{left\text{-}up}<.001$, $p_{left\text{-}down}=.001$). Differences between right-left and up-down keys were not significant (all $ps>.5$). The interaction between choice and key was not significant ($F(3,135) = 2.25$, $p=.107$, $\eta^2 = .05$).

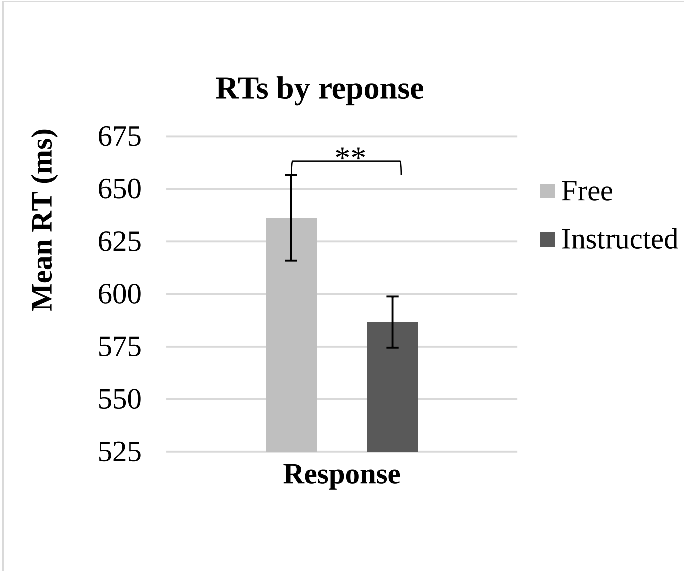


Figure 4.6 Mean RTs in the free-choice and instructed-choice conditions (** *p*<.001). Error bars represent SEM.

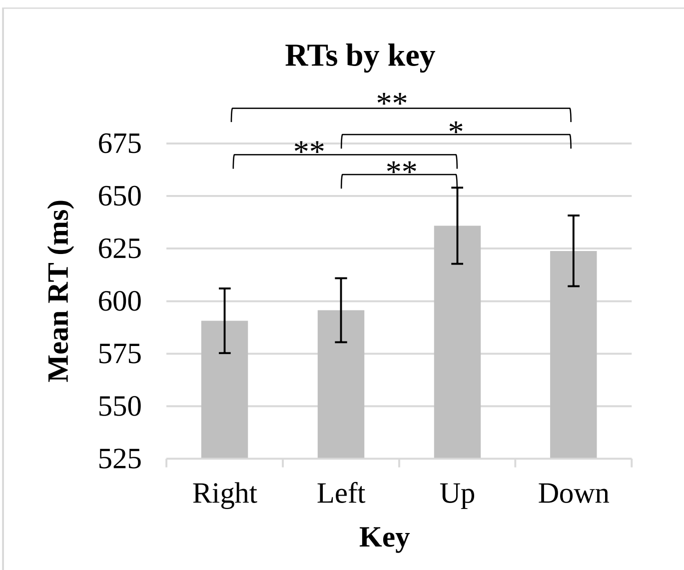


Figure 4.7 Mean RTs in pressing each key (* *p*<.05, ** *p*<.001). Error bars represent SEM.

4.4.5 Pleasantness ratings for the outcome chords

As noted before, key press outcomes were one of two consonant (perfect fifth and perfect fourth) and two dissonant (minor second and major second) chords. We calculated the mean pleasantness ratings for each valence and ran paired samples t tests to compare the ratings. The test showed that consonant chords were perceived as more pleasant (M=4.51, SD=.64) than dissonant chords (M=2.48, SD=.42); $t(1,45)=18.73$, $p<.001$. We also conducted to a one-way repeated measures ANOVA with chord (perfect fifth, perfect fourth, minor second, major second) as a within subjects factor in order to examine differences across the four chords. The test revealed a significant main effect of chord ($F(3,135) = 255.90$, $p<.001$, $\eta^2 = .85$). Post hoc tests indicated that perfect fifth (M=4.70, SD=.81) was perceived as more pleasant compared to perfect fourth (M=4.33, SD=.57, p=.001), major second (M=3.14, SD=.59, $p<.001$), and minor second (M=1.82, SD=.46, $p<.001$). Perfect fourth was also perceived as more pleasant compared to both minor second ($p<.001$) and major second ($p<.001$). Finally, minor second was perceived as more unpleasant compared to major second ($p<.001$). These results overall confirm that the consonant and dissonant chords we included in the experiment were indeed classified as pleasant and unpleasant action-outcomes.

4.4.6 Key selection in the free condition

We also examined how the choice of key among for key alternatives in the free condition was distributed. Accordingly, the proportions of selecting right, left, up, and down keys were 28.79% (SD=11.61), 27.80% (SD=8.87), 21.27% (SD=7.27), and 22.13% (SD=8.51), respectively. A one-way repeated measures ANOVA with key (right, left, up, down) as within subjects factor revealed a main effect of key ($F(3,135) = 6.01$,

p=.002, η^2 = .85). Post hoc comparisons showed that the right key was selected more often than the up key (p=.019) and the left key was selected more often than the up key (p=.009). No other comparisons were significant (p>.05).

4.4.7 Correlation Analyses

4.4.7.1 *FoC and pleasantness ratings*

In order to examine the relationship between FoC ratings and pleasantness ratings, we first calculated the difference in the mean FoC ratings in each choice (free, instructed) between pleasant and unpleasant outcomes ($M_{Free(pleasant\text{-}unpleasant)}$=1.00, $SD_{Free(pleasant\text{-}unpleasant)}$=91; $M_{Instructed(pleasant\text{-}unpleasant)}$=.80, $SD_{Instructed(pleasant\text{-}unpleasant)}$=73). These differences were then subjected to bivariate Pearson correlation tests with the difference in the mean pleasantness ratings between pleasant and unpleasant outcomes ($M_{(pleasant\text{-}unpleasant)}$=2.25, $SD_{(pleasant\text{-}unpleasant)}$=.73). The test revealed that the difference in the FoC ratings between the pleasant and unpleasant outcomes for both free (r=.50, p=.015) and instructed (r=.47, p=.024) conditions were significantly correlated with the difference in the pleasantness ratings, indicating that the more distant participants perceived the valence of the outcomes, the greater differences were felt in the FoC ratings between pleasant and unpleasant outcomes (see Figures 4.8 & 4.9).

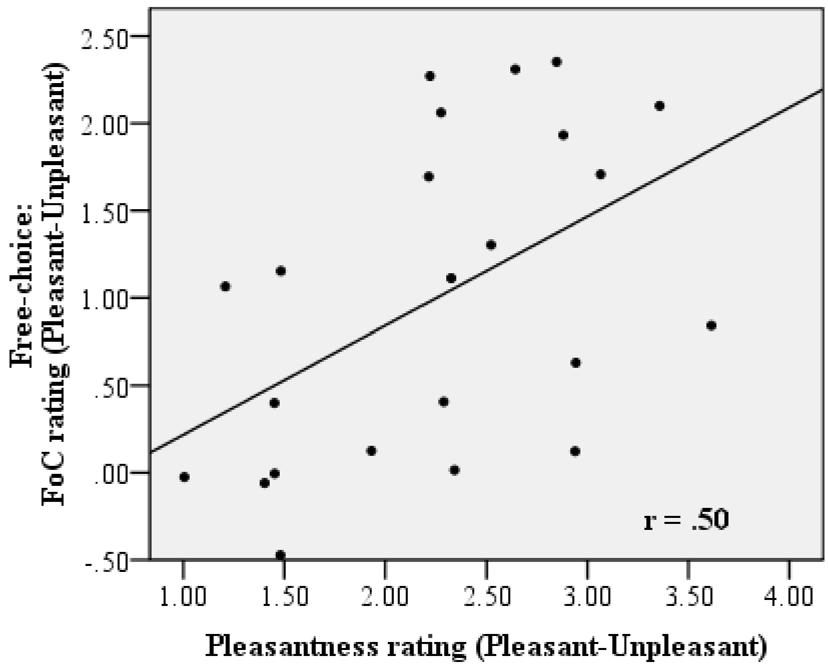


Figure 4.8 Correlation between the pleasant versus unpleasant difference scores of FoC and pleasantness ratings in the free-choice condition.

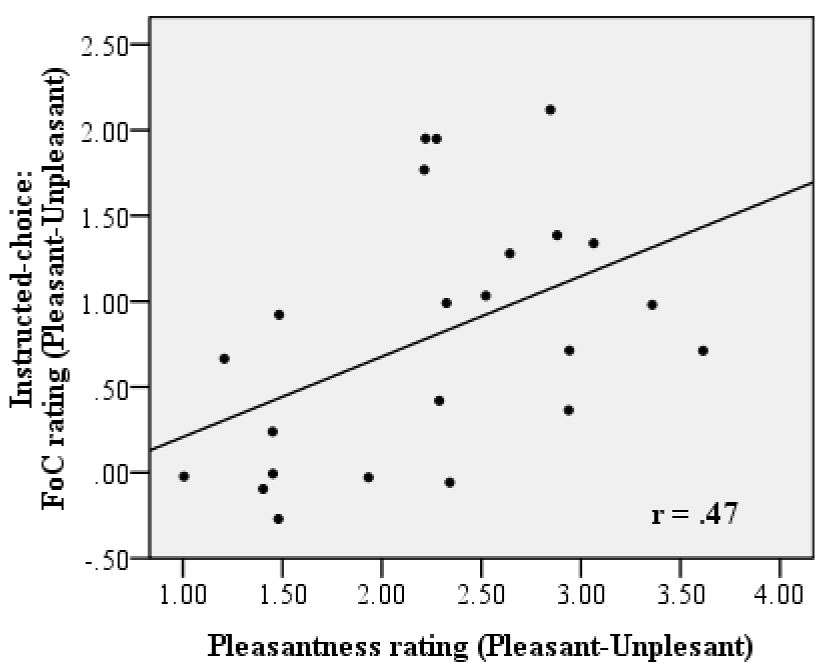


Figure 4.9 Correlation between the pleasant versus unpleasant difference scores of FoC and pleasantness ratings in the instructed-choice condition.

4.4.7.2 *Interval estimations and pleasantness ratings*

The same line of correlation analyses as conducted between FoC and pleasantness ratings showed, between the inter interval estimations and pleasantness ratings, differences in the interval estimations ($M_{Free(pleasant-unpleasant)}$=-3.32, $SD_{Free(pleasant-unpleasant)}$=44.02; $M_{Instructed(pleasant-unpleasant)}$=-9.20, $SD_{Instructed(pleasant-unpleasant)}$=48.48) and the pleasantness ratings outcomes ($M_{(pleasant-unpleasant)}$ =1.81, $SD_{(pleasant-unpleasant)}$=.69) between pleasant and unpleasant outcomes did not correlate in either free or instructed conditions (*r*s<.1, *p*s>.7).

4.4.7.3 *Interval estimations and FoC ratings*

We examined the relationship between the interval estimations and FoC ratings by subjecting the means of these measures in each choice (free, instructed) and valence (pleasant, unpleasant) condition to bivariate Pearson correlation analyses. The tests, however, did not reveal any significant correlation (*r*s<.2, *p*s>.3).

4.5 Discussion

Previous research has provided evidence that distinct neural structures are involved in freely selected versus externally determined actions (Cunnington et al., 2002; Filevich et al., 2013; Forstmann et al., 2008, 2006; Waszak et al., 2005). Moreover, subjective experience of actions in these two modes appears to be influenced by the compatibility of the source specifying the *type* and *timing* of actions (Wenke et al., 2009) as well as by the *number of action alternatives* (Barlas & Obhi, 2013). A separate line of research examined the effect of outcome valence and showed that positive or desirable outcomes are associated with stronger SoA than negative or undesirable outcomes (Barlas & Obhi, 2014; Takahata et al., 2012; Yoshie & Haggard, 2013). In the present study, we investigated the influence of both of these factors on intentional binding and FoC ratings when both free and instructed actions randomly produced pleasant and unpleasant outcomes. A strength of the current study is that we determined the effects of these variables on both implicit and explicit measures of SoA.

To begin with, our results with the pleasantness ratings obtained at the end of interval estimation and FoC rating tasks confirmed that the consonant auditory stimuli were indeed perceived as more pleasant sounding than the dissonant stimuli, in line with the previous investigations of consonance preference (Bidelman et al., 2009; McDermott & Hauser, 2004; Schellenberg & Trehub, 1996b; Tramo et al., 2001).

One important finding is that both interval estimations and FoC ratings indicated stronger SoA when action was freely chosen as opposed to when action was instructed. This finding is an important contribution because research on SoA has rarely examined the effects of freedom of choice (or self-involvement) in action selection. The finding of higher FoC ratings in the free-choice condition is consistent with the notion that people tend to feel stronger control over actions that are based on self-generated decisions and intentions (Haggard, 2008; Sebanz & Lackner, 2007).

Why might we have observed more binding in the free versus fixed choice conditions? One interpretation of stronger binding in the free-choice condition relates to the underlying neural structures involved in free action selection and binding. Previous research has consistently highlighted the importance of the SMA in internally generated action selection (Cunnington et al., 2002; Filevich et al., 2013; Lau, Rogers, Haggard, & Passingham, 2004; Lau, Rogers, & Passingham, 2006; Waszak et al., 2005). Importantly, recent studies examining the neural correlates of the intentional binding effect found that activity in the SMA was positively correlated with the degree of binding (Kühn et al., 2012). Furthermore, disruption of pre-SMA, in particular, caused a reduction in the binding effect (Cavazzana et al., 2015; Moore, Ruge, Wenke, Rothwell, & Haggard, 2010a). Based on these studies, it seems plausible that greater SMA activation in the free-choice condition in our study could have led to greater binding of actions and their effects.

Regarding outcome valence, we previously reported that the same pleasant chords we used in the present experiment led to stronger binding compared to more unpleasant outcomes (Barlas & Obhi, 2014). Our current results, however, did not reveal any significant effect of outcome valence on interval estimation. It is, however, important to note that key presses and the ensuing chords were non-contingent in the current study while in the earlier experiment one of the two keys (right or left key) would consistently produce either a pleasant or unpleasant chord. Thus, in the current study, pre-movement processes could not predict specific outcomes (Blakemore et al., 2001; Frith et al., 2000). Given the importance of premotor prediction and action-effect contingency (Haggard, 2005; Moore & Haggard, 2008; Moore, Lagnado, Deal, & Haggard, 2009), the null finding for outcome valence might be a reasonable observation in our particular study design. Additionally, although retrospective processes have previously been shown to influence binding (Moore & Haggard, 2008), the current results did not demonstrate such effects, at least with respect to the type of outcome produced. However, participants reported having a stronger FoC over the pleasant compared to the unpleasant outcomes. Correlation analyses also revealed that the FoC and pleasantness ratings were significantly correlated when the corresponding ratings for pleasant and unpleasant chords were contrasted. This finding is in line with the notion of the self-serving bias.

Another very important finding in the current study is the interaction between choice level and outcome valence on FoC. Specifically, participants felt more in control of pleasant outcomes when these outcomes were produced by freely selected key presses than when they were produced by instructed key presses. The FoC ratings, however, did not differ as a function of choice for the unpleasant outcomes. This result might again be associated with the self-serving bias in that participants could have felt even stronger control over pleasant outcomes when these outcomes were produced by the participants' own choice of actions. In contrast, the desire to mitigate perceived authorship of unpleasant outcomes might over-ride any differences relating to free action versus instructed action. This finding has potential implications for social situations in which individuals are forced to perform actions that produce unpleasant outcomes (e.g., in the classic Milgram obedience experiments, Stanley, 1963). In such cases, the current results suggest that it may be the outcome that prevails, with the processes leading to the outcome being given less weight in the computation of agentic experience when the outcome is negative.

Consistent with previous reports, we also found that FoC ratings were lower for longer action-outcome delays. This supports the view that action-outcome intervals are important retrospective cues that influence FoC judgments (Chambon & Haggard, 2012; Chambon et al., 2013; Sidarus et al., 2013; Wenke et al., 2010).

The finding that RTs were longer in the free-choice compared to instructed-choice condition is in accordance with a previous finding that free-choice conditions (2 and 3 level of choice) required more time for participants to make a selection compared to a forced-choice condition (Forstmann et al., 2006). Longer RTs in the free-choice condition presumably reflect more complex decision processes in action selection. An important question for future studies is to understand the potential relationship between such action selection processing and the SoA.

One aspect of our design that could be seen as a limitation is that the actions in our experiment randomly produced one of four chords, thereby making actions and outcomes non-contingent. It has previously been pointed out that voluntary/intentional actions often involve anticipation of outcomes (Elsner & Hommel, 2001; Elsner et al., 2002; Haggard, 2008; Herwig et al., 2007). In this regard, some may argue that the free-choice actions in our study were not "normal" voluntary/intentional actions. However, we sometimes make decisions about actions without having a clear pre-specification of the consequences. Examination of actions that are not predictive of specific outcomes also allowed us to determine the pure effects of free-choice versus fixed action on SoA. We suggest that the free-choice actions in our study, while being non-predictive of outcome, did involve other decision processes that are fundamentally linked to naturalistic volitional action.

Another possible limitation of our study is that the free-choice condition included all possible action alternatives – that is, we did not systematically vary the degree of choice across many alternatives. In a previous study we found that a medium level of choice (3 keys) did not differ from either high level of choice (7 keys) or no-choice conditions (Barlas & Obhi, 2013). Thus, further work is needed in which the number of action alternatives is parametrically varied, and effects on SoA (binding and FoC) are assessed. One interesting possibility is that beyond a certain "optimum" choice level, SoA may be reduced. Knowing the relationship between choice level and agency has important implications for product designers – the level of choice that optimizes agency experience might be critical for the design of devices as varied as smart phones to self-driving vehicles. Given that choices are often effortful (e.g., Bettman, Johnson, & Payne, 1990) it is also important to investigate how this variable affects different measures of SoA and furthermore how this effort might interact with choice to affect agency. In a follow-up study, we are implementing our current design but with four choice levels and are also collecting subjective effort ratings to examine how perceived effort in selection affects agency.

To conclude, the findings of the present study underline the importance of freedom to choose actions and the valence of action-outcomes on the SoA. It appears that one's freedom to select an action among several alternatives has a crucial impact on both the low level SoA, indexed by intentional binding, and higher level feelings of control. For conscious judgments of control, the valence of these outcomes is also important. Specifically, the conscious FoC is boosted when we are *both* free to select our actions *and* when these actions produce more desirable outcomes. More work is necessary to fully understand whether freedom always produces a greater SoA or whether there are certain situations in which too much freedom, for example, can diminish the experience of control.

The objective of the following chapter is to extend the present study's manipulation regarding the choice (i.e., free vs. instructed) to a wider range of actions alternatives (i.e., ranged from 1 to 4) and again examine the impact of choice level and outcome pleasantness on the SoA.

Chapter 5

Experiment 4: Choice-level, Outcome Valence, and the Sense of Agency

Contents

Under review as:

Barlas, Z., Hockley, W. E., & Obhi, S. S. Choice-level, outcome valence, and the sense of agency.

5.1 Abstract

We examined the influence of the action choice-level (varied from one to four) and the outcome valence on the sense of agency (SoA). Participants performed either freely chosen or instructed key presses which could produce pleasant or unpleasant chords. We obtained estimates of the key press-chord intervals, feeling of control (FoC) ratings over the outcomes, and subjective ratings of mental effort in key selection. Interval estimates were used to index intentional binding - the perceived temporal attraction between actions and their outcomes. Results showed stronger binding in the four-choice condition compared to remaining choice-level conditions. FoC ratings were increased as the choice-level varied from one to four, and were higher for pleasant than unpleasant outcomes. Additionally, greater effort was experienced in performing instructed than freely chosen actions. These results emphasize the importance of freedom and choice-level in action selection and the outcome valence on the SoA.

5.2 Introduction

Freedom in action selection is not always an all-or-none phenomenon. That is, our freedom to choose an action can also be constrained by the number of action alternatives available in a certain context. For example, one who wants to engage in regular physical activities can choose to join a basketball or football team or go to the gym depending on the alternatives available in their environment and society. In a small town, the only option can be going to a gym while in metropolitan cities there can be a greater variety of options. In addition to the variety of alternatives, one's decision on which activity to engage would also involve their needs and desires regarding what is expected out of these activities. For instance, one might find playing basketball more enjoyable than going to the gym while another would rather go to the gym regularly to achieve their goals with greater level of exercise. Furthermore, these decisions could be made by either one's self or others. Indeed, according to Schwartz (2012), the most fundamental value of choice is that freedom to choose enables people to express their autonomy and preferences as an individual. Given the prevalence of choice and making decisions on actions, one interesting question is how the subjective experience of agency would be affected under the scenarios similar to those exemplified above.

Several views consider the SoA to be closely linked to the notion of *free will* (Aarts & van den Bos, 2011; Haggard et al., 2004, 2002) and choice has long been the subject of theories of decision making and social psychological studies (e.g., Kitayama & Snibbe, 2004; Savani, Markus, Naidu, Kumar, & Berlia, 2010; Schwartz, 2012). Furthermore, most human actions are performed to achieve a specific goal or cause changes in the environment (Elsner & Hommel, 2001; Elsner et al., 2002; Haggard, 2008; Herwig et al., 2007). Given these views, it is surprising that research on agency has scarcely examined the relationship between the SoA and choice, freedom, and the value of action-outcomes.

As previously surveyed (see Chapters 2-4), the majority of previous research in this regard have focused on the source (i.e., self vs other) of either what (Sebanz & Lackner, 2007; Wenke et al., 2009) or when (Jahanshahi et al., 1995; Obhi & Haggard, 2004; Wenke et al., 2009) dimension of action selection. Other studies examined the effect of selection fluency on the SoA by manipulating the compatibility between action primes and performed actions (Chambon & Haggard, 2012; Damen et al., 2014; Sidarus et al., 2013; Wenke et al., 2010). These studies, overall, suggested that self-generated actions and effortless processing of action selection (see Chapter 6) can lead to stronger SoA. With respect to the influence of outcome valence on the SoA, it was found that outcomes that are attached to positive or rewarding values enhanced the binding effect (Aarts et al., 2012; Takahata et al., 2012).

In the present thesis, thus far, we examined the issue regarding how the SoA would be influenced in a context with varying actions and differentially valued outcomes was examined from different perspectives. First, Chapter 2 examined the conditions in which on the number of alternative actions was varied while the outcome of each and every alternative was the same. Briefly put, the number of action alternatives was manipulated as fixed-choice (i.e., instructed), three-choice, and seven-choice. The results of this study showed that the amount of binding, as indirectly indexing the SoA, was strongest in the seven-choice condition and weakest in the fixed-choice condition. Second, Chapter 3 manipulated the valence of action-outcomes while the number of actions was fixed to two alternatives. The findings of this study provided evidence that pleasant or desirable outcomes lead to stronger sense of subjective control compared to unpleasant outcomes, in compliance with the notion of self-serving bias (Duval & Silvia, 2002; Miller & Ross, 1975; Taylor & Brown, 1994). Thirdly, in Chapter 4, we examined how intentional binding and subjective judgments of control were influenced when the number of action alternatives was set to four and participants could perform free or instructed actions that produced either pleasant or unpleasant outcomes. The results of this study showed that both binding and subjective control over action-outcomes were stronger when actions were freely selected compared to when they were externally determined. Moreover, pleasant outcomes led to greater judgments of control.

One important note to point out regarding the study of Chapter 2 is that the type of actions in each set of alternatives was the same. More clearly, the medium level always included the same three buttons among seven alternatives and the button in the no-choice was kept constant. Although the study in Chapter 4 ameliorated the design in that the specified key in the instructed condition was dynamically alternating among four different keys, this study did not include more diverse levels of choice. To expand on the issue at hand, a further objective is to investigate the SoA under conditions in which outcomes with different degree of pleasantness are produced by actions that are selected among dynamically changing types of actions available at varying choice-level.

The study in the present chapter, therefore, aims to advance the designs of the previous studies such that the free-choice is more varied in terms of the number of action alternatives. More specifically, the number of available key alternatives was set at four levels varying from one (instructed) option to two, three, and four options. As in Chapter 4, each key press could produce either a pleasant or an unpleasant chord after one of three intervals (100 ms, 300 ms, and 500 ms) and between subjects, we obtained both the interval estimations of key press-chord delays and FoC ratings over the chords. Another important difference in the current study is that in a post-experiment task, participants rated how much effort they felt when producing the key presses in each choice-level condition. This was to explore whether the subjectively experienced effort in action selection could vary depending on the choice-level and whether a relationship between the measures of the SoA and subjective effort could be observed. We expected to find that interval estimations would systematically get shorter while the FoC ratings would increase as the choice-level increased from one to four. Regarding the valence of the outcome chords, we did not expect to find any differences in the perceived intervals between pleasant and unpleasant chords. As noted before, this prediction was based on our previous finding (see Chapter 4) that outcome valence did not influence the binding when the key presses and chords were not contingent. FoC ratings, however, were expected to be higher over pleasant than unpleasant chords in line with our previous findings reported in Chapter 3 and Chapter 4.

5.3 Method

5.3.1 Participants

In total, 44 undergraduate students (14 male, 1 left-handed, M_{age} = 18.86, *SD*= 1.56) from Wilfrid Laurier University took part in the study. 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. Compensation for participating in the study was 1 course credit.

5.3.2 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: 1600x1200). Presentation of all stimuli was centered on a white background. Responses were made on a 5-key response pad as in Barlas et al. (2016). On this pad, four keys were placed on the right, left, up, and down side of the central key. An optical wheel mouse was used to indicate responses on visual analogue scales presented on the screen for interval estimation, FoC rating, and effort rating tasks. The interval estimation scale was ranged from 1 to 1000 ms and marked at 50 ms intervals. FoC and effort rating scales were 6-point and marked 0.5 point intervals.

Auditory stimuli consisted of a consonant (perfect fifth) and a dissonant (minor second) piano chords. These chords were selected based on the subjective pleasantness ratings obtained in previous studies (Barlas et al., 2016; Barlas & Obhi, 2014), according to which perfect fifth and minor second were rated as the most pleasant and unpleasant chords, respectively. These chords were recorded using Audacity 2.0.3, sampled at 44.1 kHz with a 16 bit stereo format. Each chord was 1 s in duration and was presented at 60 dB through the headphones.

5.3.3 Procedure

Each group of participants were first familiarized with the instructions and the stimuli, and completed 15 practice trials. There were 288 trials in total for each of the interval estimation and FoC rating tasks. The trials were presented in a random order in 6 mixed blocks with 48 trials each. After completing each block, the experiment paused to allow participants to take a break upon their will, and continued after the experimental instructions for each task were reminded on the screen.

Each trial began with a 1.5 s presentation of the image representing the central key on the response pad. Participants were told to rest their left index finger on the central key when this image was presented. The following screen displayed the target image showing the central key surrounded with varying number of keys, which was determined by the choice-level (see Figure 5.1). In the one-choice (instructed) condition, only one of four keys (right, left, up, down) was presented. Two-choice condition included one of six different two-key combinations (right-left, right-up, right-down, left-up, left-down, up-down) and three-choice condition presented one of four three-key combinations (right-left-up, right-left-down, right-up-down, left-up-down). Finally, in the four-choice condition all four keys were displayed by the target image. In the free choice conditions thus, participants were free to choose among two to four different options. The target image remained on the screen until one of four keys were pressed. Participants were told to respond as fast as possible and avoid giving stereotyped responses in the free-choice conditions. In case of an erroneous key press in the one-choice, two-choice, and three-choice conditions, a warning message ("error in key press") appeared on the screen and participants clicked on the screen to move on to the next trial. A valid response was followed by one of three delays (100 ms, 300 ms, 500 ms) before one of two chords (perfect fifth, minor second) was presented for 1 s though the headphones. In the interval estimation task, participants were told that the delay between their key press and the onset of the tone could randomly vary between 1ms and 1000 ms and they were asked to indicate their estimation of this delay using the interval estimation scale on the screen. No prior training was given for interval estimations. In the FoC rating task, a 6-point visual analogue scale (1: the lowest level of control; 6: the highest level of control) was presented at the end of each trial and participants were required to indicate the degree of self-control they felt over the production of the chord. They were told not to base their judgments on how fast or accurate were their key presses. For both measures, participants used the mouse with their right hand and moved the cursor to any point on the scale and clicked to indicate their temporal or FoC judgments. Inter-trial interval was set to 500 ms during which a blank screen was presented.

Both the interval estimation and the FoC rating tasks were followed by the effort rating task which measured the perceived mental effort in choosing which key to press. This task consisted of two blocks of 48 trials (96 in total). The trial procedure was exactly the same as that in the interval estimation and FoC rating tasks with the exceptions that no chord was presented after the key presses and the trials ended with a 6-point effort rating scale displayed on the screen. Using this scale, participants indicated how much mental effort they experienced when choosing which key to press (1: very low; 6: very high).

At the end of the experiment, participants were debriefed about the goal of the study and thanked for their time.

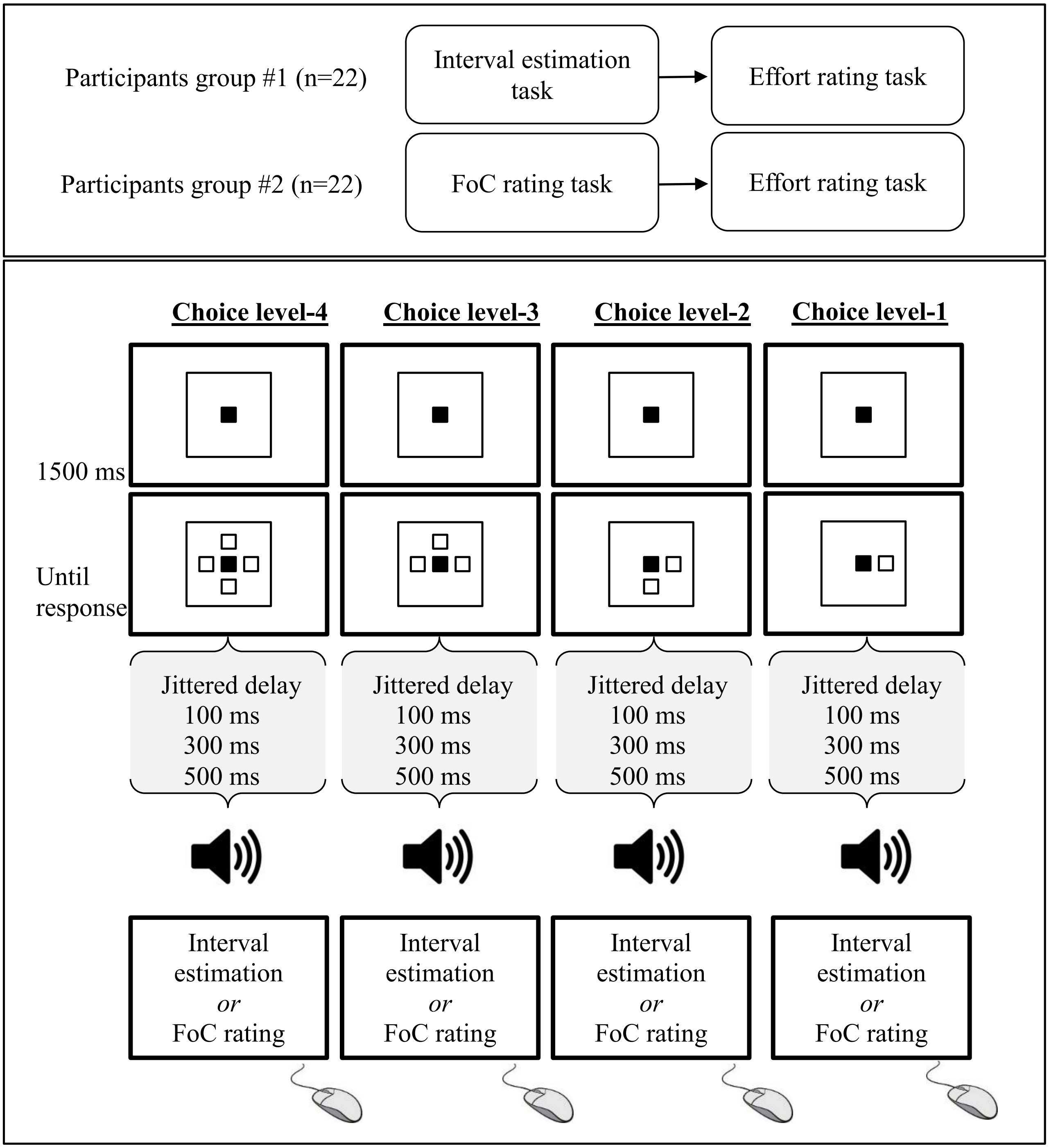


Figure 5.1 Schematic illustration of the tasks completed by each group of participants (upper panel) and the sample trial procedure in the interval estimation and FoC rating tasks demonstrated for each choice-level (lower panel).

5.3.4 Data processing

5.3.4.1 *Trial exclusion*

For the interval estimation task, trials with RTs or interval estimations being three standard deviations away from the mean, or those with incorrect responses (pressing the wrong key in all but four-choice condition) were excluded (M_{excluded} = 2.57%, *SD*= .84% of all trials). The same criteria (except the interval estimation criterion) were also processed in the FoC rating task data (M_{excluded} = 2.33%, *SD*= 1.13% of all trials).

5.3.5 Data analyses

We used repeated measures analysis of variance (ANOVA) to examine the effects of choice-level (one, two, three, four) and valence (pleasant, unpleasant) on the interval estimations and FoC ratings. Combining the data from both interval estimation and FoC rating tasks, RTs were analyzed as a function of choice-level and key (right, left, up, down) while effort ratings were analyzed factoring in the choice-level. Greenhouse-Geisser correction was used where Mauchly's test of sphericity was violated. *Post hoc* multiple comparisons[3] were performed where differences across variable levels were examined. Additionally, two-tailed paired samples t-tests and one sample t-tests were conducted where appropriate. All data analyses were conducted using SPSS (version 16.0) and the significance level was set to .05.

[3] Since we had directional predictions (see page 106) indicating increased binding and FoC with increased choice-level based on the previous findings (Chapter 1 and Chapter 3), we did not perform Bonferroni correction on the multiple comparisons in this experiment.

5.4 Results

5.4.1 Accuracy

Mean proportion of selecting a valid key (in the one-, two-, and three-choice conditions) that is among the presented key alternatives was 99.11% (*SD*=1.05).

5.4.2 Interval estimations

We calculated the mean interval estimations for each condition (see Table 5.1) and ran a 4 x 2 x 3 repeated measures ANOVA with choice-level (one, two, three, four), valence (pleasant, unpleasant), and delay (100 ms, 300 ms, 500 ms) as within subjects factors. The analysis yielded significant main effects of both choice-level ($F(3,63) = 3.37$, $p=.046$, $\eta^2 = .14$) and delay ($F(2,42) = 94.25$, $p<.001$, $\eta^2 = .82$). Regarding the effect of choice-level, *post hoc* multiple comparisons showed that interval estimations in the four-choice condition (*M*=427.90, *SD*=112.90) was significantly shorter than all three-choice (*M*=436.20, *SD*=114.49, *p*=.046), two-choice (*M*=440.67, *SD*=115.33, *p*=.010), and one-choice (*M*=446.22, *SD*=113.73, *p*=.031) conditions (see Figure 5.2). The remaining comparisons were not significant (*p*s>.1). With respect to the interval estimations for each actual delay, *post hoc* tests revealed that interval estimations were systematically increased across 100 ms (*M*=320.39, *SD*=130.90), 300 ms (*M*=433.99, *SD*=104.22), and 500 ms (*M*=558.86, *SD*=107.21) with differences being significant at all levels (all *p*s<.001). Although the perceived intervals were shorter with pleasant (*M*=433.33, *SD*=116.64) compared to unpleasant outcomes (*M*=442.17, *SD*=111.59), the main effect of valence was not significant ($F(1,21) = 1.07$, $p=.312$). Additionally, two- or three-way the interactions among choice-level, delay, and valence were not significant (*Fs*<2, *ps*>.1).

To sum up, examination of the two main factors of interest, namely the choice-level and outcome valence showed that while the valence of the action-outcomes did not influence the interval estimations, participants perceived the action-outcome delays significantly briefer when they had the maximum number of key alternatives compared to fewer choice-levels.

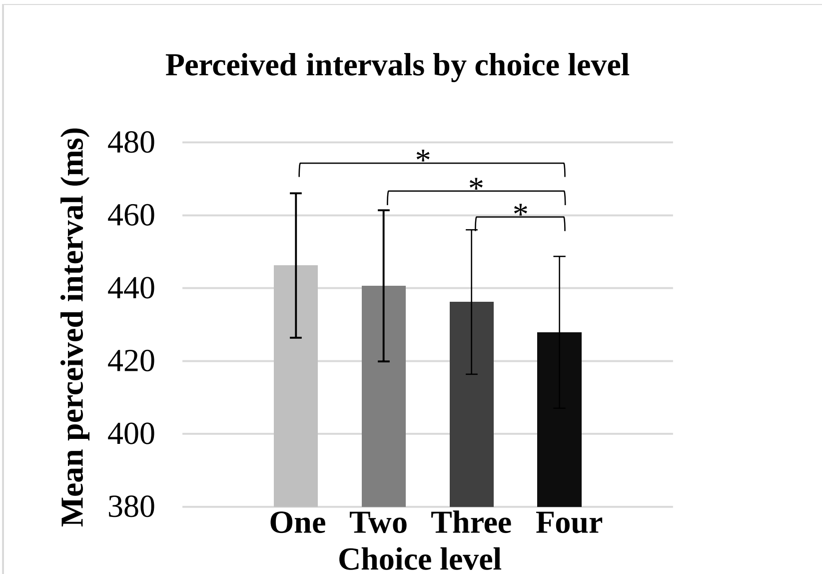


Figure 5.2 Mean perceived intervals as a function of choice-level (* *p*<.05). Error bars represent SEM.

Table 5.1 Means and standard deviations of interval estimations in each choice-level, outcome valence, and actual delay condition.

Delay	**100 ms**		**300 ms**		**500 ms**	
Valence / **Choice-level**	*Pleasant*	*Unpleasant*	*Pleasant*	*Unpleasant*	*Pleasant*	*Unpleasant*
One	313.20 (±134.26)	321.38 (±138.63)	443.45 (±104.38)	338.59 (±89.90)	577.18 (±111.39)	583.53 (±103.81)
Two	329.39 (±140.31)	335.31 (±129.13)	417.49 (±102.99)	458.07 (±119.07)	543.65 (±108.14)	560.33 (±92.32)
Three	322.27 (±127.55)	328.99 (±121.90)	429.58 (±116.66)	424.55 (±94.18)	546.95 (±112.29)	564.90 (±114.37)

Four	305.08 (±137.82)	307.50 (±117.59)	429.28 (±97.76)	430.95 (±108.85)	542.69 (±106.10)	551.89 (±109.27)

5.4.3 FoC ratings

Similar to the interval estimations analyses, mean FoC ratings were calculated for each condition (see Table 5.2) and were subjected to a 4 x 2 x 3 repeated measures ANOVA with choice-level (one, two, three, four), valence (pleasant, unpleasant), and delay (100 ms, 300 ms, 500 ms) as within subjects factors. The test revealed significant main effects of choice-level ($F(3,63) = 9.11$, p=.005, $\eta^2 = .30$) and valence ($F(1,21) = 26.43$, p<.001, $\eta^2 = .56$). *Post hoc* multiple comparisons across choice-levels showed that FoC ratings were significantly higher in the four-choice condition (*M*=4.09, *SD*=1.00) compared to all three-choice (*M*=3.68, *SD*=.71, *p*=.005), two-choice (*M*=3.43, *SD*=.70, *p*=.007), and one-choice (*M*=3.02, *SD*=1.04, *p*=.005) conditions. Additionally, participants felt significantly more in control of the chords when they had three key alternatives compared to both two (*p*=.023) and one choice (*p*=.009) conditions. Finally, FoC ratings in the two-choice condition was significantly higher than the one-choice condition (*p*=.007). Thus, FoC ratings were systematically increased as the number of key alternatives was increased from one to four (see Figure 5.3). Regarding the main effect valence, we found that participants reported higher FoC ratings over the pleasant (*M*=3.97, *SD*=.83) than the unpleasant chords (*M*=3.14, *SD*=.89). The main effect of delay did not reach significance ($F(2,42) = 3.66$, p=.066, $\eta^2 = .15$) although the FoC ratings were systematically decreased as the delay increased from 100 ms (*M*=3.67, *SD*=.96) to 300 ms (*M*=3.61, *SD*=.80) and to 500 ms (*M*=3.39, *SD*=.82). Finally, two- or three-way interactions among choice-level, valence, and delay were not significant (*Fs*<2, *ps*>.2).

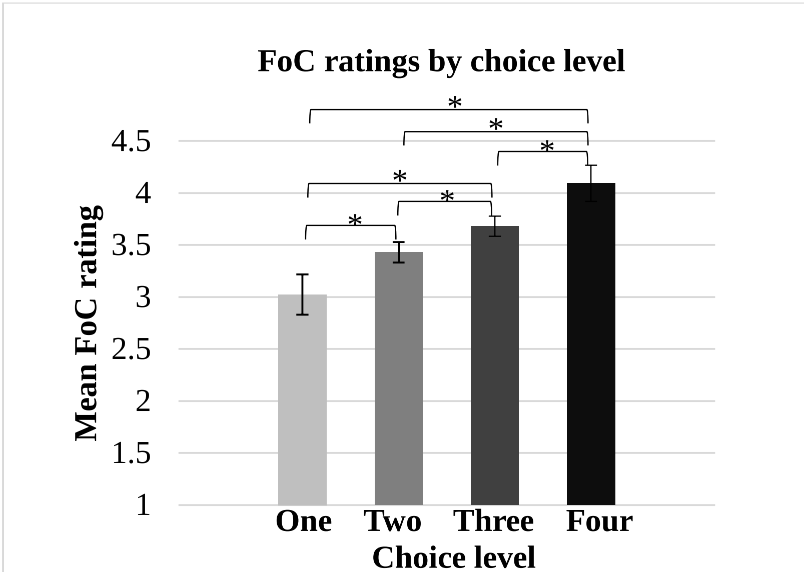


Figure 5.3 Mean FoC ratings as a function of choice-level (* $p<.05$). Error bars represent SEM.

Table 5.2 Means and standard deviations of FoC ratings in each choice level, outcome valence, and actual delay condition.

Delay	100 ms		300 ms		500 ms	
Valence / Choice level	*Pleasant*	*Unpleasant*	*Pleasant*	*Unpleasant*	*Pleasant*	*Unpleasant*
One	3.41 (±1.27)	2.85 (±1.18)	3.53 (±1.07)	2.66 (±.94)	3.29 (±.97)	2.40 (±.82)
Two	3.94 (±.74)	3.15 (±.87)	3.86 (±.66)	3.04 (±.65)	3.73 (±.63)	2.87 (±.63)
Three	4.19 (±.70)	3.39 (±.96)	4.18 (±.60)	3.37 (±.65)	3.89 (±.67)	3.05 (±.69)
Four	4.67 (±.87)	3.79 (±1.10)	4.60 (±.81)	3.62 (±1.05)	4.40 (±.99)	3.48 (±1.19)

In summary, examination of the FoC ratings suggested that participants FoC over the outcome chords were increased as these chords were produced by freely selected than externally instructed key presses and when the chords were pleasant than they were unpleasant.

5.4.4 Response times (RTs)

We examined the RTs across interval estimation and FoC rating tasks by a 4 x 4 repeated measures ANOVA with choice-level (one, two, three, four) and key (right, left, up, down) as within subjects factors. The test revealed significant main effects of choice-level ($F(3,120) = 9.88$, $p=.001$, $\eta^2 = .20$) and key ($F(3,120) = 34.30$, $p<.001$, $\eta^2 = .46$). The interaction between choice-level and key was not significant ($F(9,360)=1.80$, $p=.99$). Regarding the main effect of choice-level, post hoc multiple comparisons indicated that RTs were significantly faster in the one-choice condition (*M*=629.44, *SD*=103.14) compared to all two- (*M*=669.62, *SD*=129.79, $p<.001$), three-(*M*=674.05, *SD*=151.81, $p=.001$), and four-choice (*M*=662.43, *SD*=154.77, $p=.011$) conditions. Moreover, RTs in the four-choice condition was significantly faster than that in the three-choice condition ($p=.029$). The remaining differences were not significant (*ps*>.3) (see Figure 5.4). Examination of the main effect of key showed that RTs were faster when pressing the right key (*M*=634.55, *SD*=131.72) compared to both up (*M*=691.78, *SD*=143.02, $p<.001$) and down (*M*=671.95, *SD*=135.21, $p<.001$) keys. Pressing the left key (*M*=637.25, *SD*=129.56) was also significantly faster compared to both up ($p<.001$) and down ($p<.001$) keys. Finally, pressing the down key compared to the up key was significantly faster ($p=.010$) (see Figure 5.5).

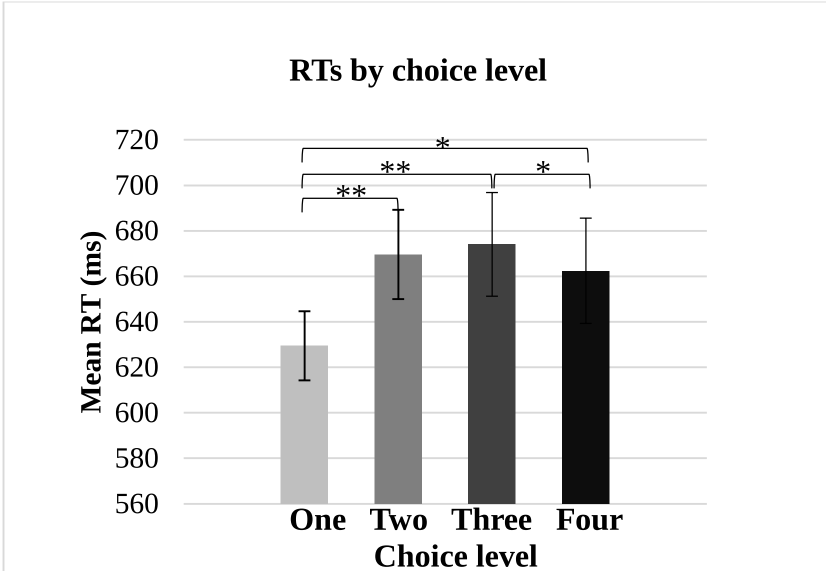


Figure 5.4 Mean RTs as a function of choice-level (* *p*<.05, ** *p*<.001). Error bars represent SEM.

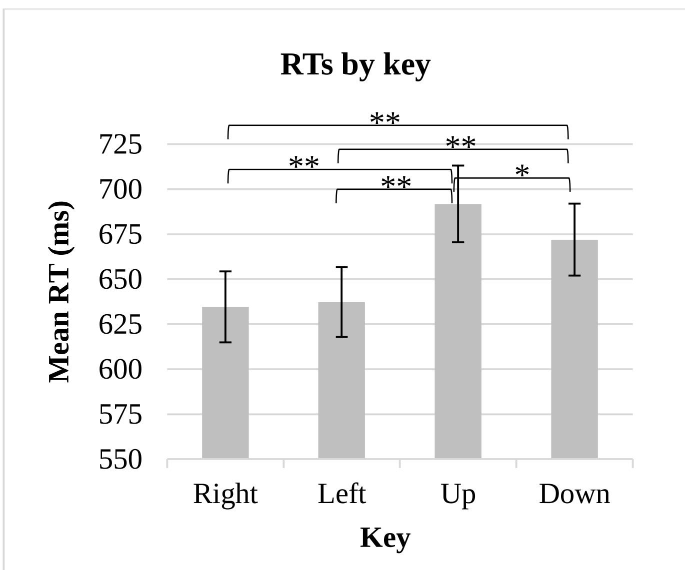


Figure 5.5 Mean RTs as a function of key (* *p*<.05, ** *p*<.001). Error bars represent SEM.

5.4.5 Effort ratings for key selection

As we sought to examine the degree of mental effort felt when determining the key in each choice-level condition, we analyzed the mean effort ratings by a one-way repeated measures ANOVA with choice-level (one, two, three, four) as within subjects factor. Accordingly, the test showed that the main effect of choice-level was significant ($F(3,129) = 5.71$, $p = .014$, $\eta^2 = .18$). *Post hoc* multiple comparisons suggested that participants felt significantly less effort for the key selection in the four-choice condition ($M = 2.50$, $SD = 1.02$) compared to all three- ($M = 2.88$, $SD = .64$, $p = .001$), two- ($M = 3.04$, $SD = .70$, $p = .002$), and one-choice ($M = 3.10$, $SD = 1.05$, $p = .022$) conditions (see Figure 5.6). The remaining differences were not significant ($p > .05$)

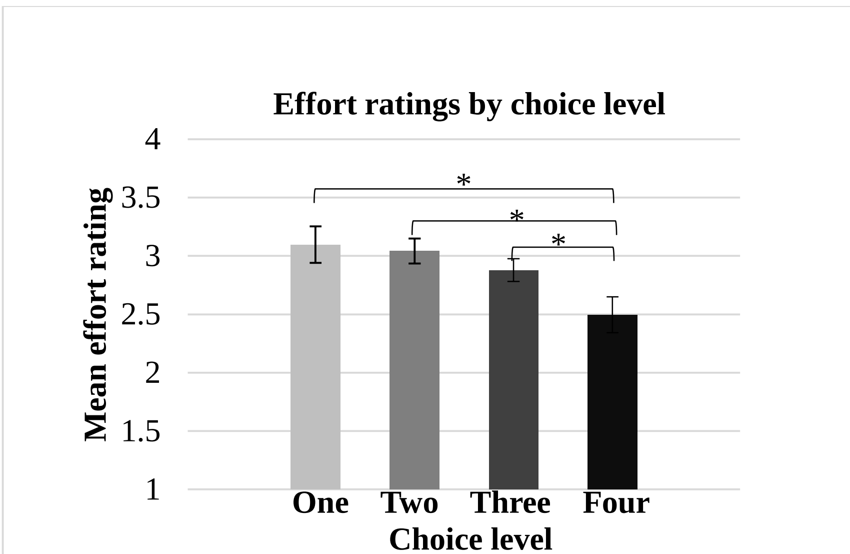


Figure 5.6 Mean effort ratings as a function choice-level (* $p < .05$). Error bars represent SEM.

5.4.6 Key selection in the multiple choice conditions

We also examined the frequency of selecting one of four keys in the multiple choice conditions. Accordingly, the proportions of selecting right, left, up, and down keys were 26.88% (*SD*=9.42), 28.29% (*SD*=9.45), 23.94% (*SD*=10.75), and 20.59% (*SD*=9.08), respectively. A one-way repeated measures ANOVA with key (right, left, up, down) as within subjects factor revealed a main effect of key ($F(3,129) = 4.08$, $p=.008$, $\eta^2 = .09$). *Post hoc* comparisons showed that the right key was selected more often than the down key ($p=.010$) and the left key was selected more often than the down key ($p<.001$). No other comparisons were significant ($p>.1$).

5.4.7 Correlation Analyses

5.4.7.1 *FoC and effort ratings*

The relationship between FoC ratings and effort ratings was examined by running Pearson correlation analyses for each choice-level condition. The tests did not reveal any significant correlation between FoC and effort ratings (*r*s<.1, *p*s>.3).

5.4.7.2 *Interval estimations and effort ratings*

We similarly examined the relationship between interval estimation and effort ratings and did not find any significant correlation between these two measures (*r*s<.3, *p*s>.1)

5.4.7.3 *Interval estimations and FoC ratings*

We examined the relationship between the interval estimations and FoC ratings by subjecting the means of these measures in each choice-level (one, two, three, four) and valence (pleasant, unpleasant) condition to bivariate Pearson correlation analyses. The tests, however, did not reveal any significant correlations between these two measures of the SoA (*r*s<.2, *p*s>.2).

5.5 Discussion

The SoA has been shown to be related to the origin of action selection (e.g., Barlas et al., 2016; Sebanz & Lackner, 2007; Wenke et al., 2009), freedom to choose among a varying number of action alternatives (Barlas & Obhi, 2013), and the valence of action outcomes (Barlas & Obhi, 2014; Takahata et al., 2012; Yoshie & Haggard, 2013). In the current study, we examined the influence of both having a range of action alternatives (one, two, three, and four options) and the outcome valence (pleasant vs. unpleasant) on intentional binding and FoC ratings, taken as the two measures of the SoA.

The results concerning the choice-level and the intentional binding effect showed that perceived intervals were systematically decreased as the number of action alternatives was increased from one to four. Importantly, significantly stronger binding (i.e., shorter estimation of the action-outcome delays) was observed in the four-choice condition compared to the remaining three-, two, and one-choice conditions while the restricted choice conditions (i.e., two- and three-choice) did not differ from the one-choice condition. We obtained similar results in a previous study (Barlas & Obhi, 2013) in which the choice-level was manipulated between one, three, and seven options and the amount of binding was found to be strongest in the seven-choice condition compared to three- and one-choice (instructed) conditions. In that study, however, the three-choice condition did not significantly differ in the amount binding from seven- and one-choice conditions while in the present study we found that the highest number of choice (four) significantly differed from the lower number of choice conditions. One important difference between these two studies, with respect to the manipulation of choice-level, is that the restricted choice conditions in the present study presented alternating set of two or three options out of four. In the earlier study, however, the three-choice condition included a fixed set of options out of seven. In the present study thus, participants had to adapt themselves to the varying alternatives of actions, which might have imposed a constraint that downgraded the freedom in these conditions compared to the fully free condition of selecting any key among four options. This is in fact an interesting question for future studies to investigate how constant versus varying set of action alternatives could influence the SoA.

In terms of the brain correlates of free selections, previous neuroimaging studies have revealed greater activation in supplementary motor area (SMA) and rostral cingulate zone (RCZ) along with dorsolateral prefrontal cortex (DLPFC) and inferior parietal lobe (IPL) when actions were freely selected as opposed to when the action was instructed (Cunnington et al., 2002; Filevich et al., 2013; Lau et al., 2004, 2006; Waszak et al., 2005). Forstmann, Brass, Koch, and Cramon (2006), for example, examined the neural correlates of free choice which was varied such that participants were either instructed on which task to perform or were free to choose among two or three options. They found that RCZ, in particular, was strongly engaged in free choice conditions compared to the instructed condition.

In another study (Van Eimeren et al., 2006), participants’ responses were guided by external visuospatial cues that indicated either an instructed response or presented two to four response options. The goal of this study was to determine the differences in the brain regions across the four choice-level conditions. Confirming the previous neuroimaging findings, the results showed increased activity in the rostral SMA and right DLPFC when free-choice conditions were contrasted with the instructed condition. However, there was no difference in activation of these areas between four choice and restricted-choice (two and three options) conditions.

Taken together, these neuroimaging studies suggest that a specific network of brain areas is associated with voluntary action selection. Greater activation in SMA in free choice of actions is particularly important for the current study as this area has been shown to be linked to the intentional binding effect (Cavazzana et al., 2015; Kühn et al., 2012; Moore et al., 2010a). Moreover, Kühn et al. (2012) have provided evidence that activity in the SMA was positively correlated with the size of binding. The role of SMA in voluntary selection and its relationship with the binding effect, therefore, could explain the finding of the current study that the amount of binding was stronger in the four- compared to one-choice condition. However, the reason why we did not observe differences in binding between restricted choice conditions (two- and three-choice) and the one-choice condition is not clear. One speculation we can suggest, as mentioned above, is that perhaps the constantly alternating choice of actions presented in the restricted choice conditions rendered the selection much more constrained as compared to the four-choice condition. Indeed, our results with the RTs showed that the restricted choice conditions took longer respond relative to four- and one-choice conditions, which nicely replicates the finding of Van Eimeren et al. (2006). Longer RTs in these conditions might thus reflect a more effortful processing during the action selection. In fact, subjective ratings of mental effort experienced in action selection confirm this line of reasoning. More clearly, participants in our study reported the one-, two, and three-choice conditions as significantly more effortful compared to the four-choice condition.

Examination of the FoC ratings obtained in our study displayed a clear distinction in the subjective experience of control across the different choice-level conditions. More specifically, participants' FoC over the outcome chords were systematically increased as the number of key alternatives was increased from one to four, and differences across all choice-levels were significant. These results not only confirm the view that self generated actions are inclined to yield stronger sense of control over their ensuing outcomes, but also demonstrate that the graded nature of freedom in action selection (Filevich et al., 2013) can have significant impact on the subjective feeling of control.

With respect to the influence of outcome valence on intentional binding, the current study did not confirm the findings of the previous two studies reporting stronger binding for pleasant versus unpleasant outcome chords (Barlas & Obhi, 2014) and reduced binding for negative compared to both positive and neutral outcomes (Yoshie & Haggard, 2013). In these studies, however, the relationship between actions and outcomes was contingent whereas in the present study, outcome chords were randomly produced by either one of four key options. In this case, the anticipations of outcomes generated by internal forward models (Blakemore et al., 2002; Frith et al., 2000; Frith, 2005; Wolpert et al., 1995; Wolpert, 1997) were probably either absent or lacking the specific information regarding the nature of the action outcomes. In our previous design of study (Barlas et al., 2016), the pleasant and unpleasant chords were also randomly produced by either free or instructed key presses and we did not the effect of outcome valence on the amount of binding. For the moment, it appears that for the outcome valence to influence binding, actions and outcomes must be contingent so that pre-movement predictions of the outcomes can be generated. Indeed, several views have noted the importance of action-outcome contingency on intentional binding (Haggard, 2005; Moore & Haggard, 2008; Moore, Lagnado, et al., 2009).

The effect of outcome valence on the subjective judgments of control, on the other hand, indicated that FoC ratings were significantly higher when the outcome chords were pleasant than they were unpleasant. This result confirms the previous studies in that positive or desirable outcomes yield stronger subjective sense of control (e.g., Barlas et al., 2016; Barlas & Obhi, 2014) over these outcomes, which could be accounted by the notion of self-serving bias (Bradley, 1978; Campbell & Sedikides, 1999).

Finally, FoC ratings have previously been found to be decreased with the longer key press-chord delays, supporting the importance of action-outcome intervals as a retrospective cue on the FoC judgments (Barlas et al., 2016; Chambon & Haggard, 2012; Chambon et al., 2013; Sidarus et al., 2013; Wenke et al., 2010). In the current study, although the changes in FoC ratings demonstrated a similar trend across three delays, the main effect of delay only approached significance. We do not interpret this result, however, as a null effect of the action-outcome delay on the FoC judgments. Before reaching a conclusion on the issue, we believe that a replication of the current study is needed.

Taken together, the common finding for both measures of SoA was that both perceived intervals and FoC ratings showed stronger SoA when actions were freely selected among the highest number of action alternatives than when the choice of action was instructed. The outcome valence, at least in the present experimental context, seems to be more prevalent as a retrospective cue as observed by its impact on the subjective judgments of control. Future studies should further investigate the interplay between choice-level in action alternatives and the effort involved in action selection.

The goal of the following chapter is to examine the SoA under conditions where free and instructed actions are preceded by presentation of action images. As such, the experiment attempted to capture the scenario in which both free and instructed actions were performed under the potential influence of external choices of actions.

Chapter 6

Experiment 5: Freedom and fluency in action selection: Can freedom outweigh the influence of action selection fluency on the sense of agency?

Contents

Under review as:

Barlas, Z., Hockley, W. E., & Obhi, S. S. Freedom and fluency in action selection: Can freedom outweigh the influence of action selection fluency on the sense of agency?

6.1 Abstract

Sense of agency (SoA) refers to the subjective experience that one has control over their actions and the outcomes of these actions. Previous research has shown that subliminal priming of actions leads to enhancement of the feeling of control (FoC) judgments when these primes are compatible with the performed actions. In the present study, participants were supraliminally presented with images of actions (i.e., lifting either index or middle finger) or a neutral image (a blank rectangle) and performed either free or instructed actions. For the free actions, participants were free to lift either the index or the middle finger regardless of the preceding prime image (neutral or action-prime) while the instructed actions required to perform either prime-compatible or prime-incompatible actions. All actions produced a tone after a jittered delay. We obtained the estimates of perceived action-outcome intervals and FoC judgments over the outcomes. Additionally, we obtained self-reports of effort experienced in action selection. We found that both interval estimations and FoC ratings indicated significantly stronger SoA in the neutral-free condition compared to all remaining modes of action selection. Moreover, these two measures of the SoA were significantly correlated. Perceived effort ratings increased across the neutral-free, primed-free, prime-compatible, and prime-incompatible conditions. Importantly, neither interval estimations nor FoC ratings was correlated with response times and both were correlated with effort ratings only in the prime-incompatible condition. Although further investigation is needed, our results suggest that freedom in action selection can outweigh the impact of selection fluency on the SoA.

6.2 Introduction

Previous chapters (i.e., Chapters 2, 4-5) examined the influence of the source of action selection (i.e., free vs. instructed) and the choice-level on the SoA. In this regard, Chapter 4 directly examined the SoA in free versus instructed actions and found that both intentional binding and FoC ratings were greater when participants freely selected an action among four alternatives compared to when they performed an instructed action. With respect to the choice-level aspect of action selection, the study presented in Chapter 2 varied the number of action alternatives (button presses) as low, medium, and high. The results showed that having the highest number of possible action alternatives resulted in the strongest binding of actions and outcomes compared to when there was only one option of action is available. The manipulation of choice-level was also applied in Chapter 5 by varying the number of action alternatives from one to four the effect of which was examined on both FoC ratings and intentional binding. The results of the study reported in Chapter 5 suggested that both binding and FoC ratings were greatest in the four-choice condition followed by three-choice, two-choice, and one-choice conditions. Overall, these results suggested that freedom to choose one's action among several alternatives boosted the SoA compared to when one performs an instructed action or when the number of action alternatives is relatively lower.

In addition to the freedom and the choice-level aspects, another important facet of action selection is the effort expended to select one action over another – sometimes referred to as the fluency of action selection. On this topic, Wenke, Fleming, and Haggard (2010) examined the effect of subliminal priming of actions on feeling of control (FoC) ratings over unpredictable outcomes (color changes on the screen). The prime images were left- and right-pointing arrows and participants were asked to press a left or right key in response to the target arrow. Critically, the primes and the targets could be either compatible or incompatible. The results showed that compatible primes facilitated the response times of key presses and more importantly, increased the FoC ratings over the outcomes. The authors suggested that the facilitation of action selection has an enhancing effect on the subjective FoC (see also Chambon & Haggard, 2012; Sidarus, Chambon, & Haggard, 2013, see Chambon, Sidarus, & Haggard, 2014 for a review).

In another study, the effect of action fluency was examined using both subliminal and supraliminal action-primes (Damen et al., 2014). The results showed that subliminal priming of actions led to stronger FoC over the outcomes when the primes were compatible with the actions compared to when they were incompatible. The awareness of the primes in the supraliminal priming condition, however, resulted in higher control ratings with the incompatible than compatible primes. Damen et al. (2014) suggested that this effect could be driven by that being aware of following external instructions suggested by the primes could undermine the SoA compared to disregarding these primes. In this study, however, actions were always freely selected in both supraliminal and subliminal priming conditions and thus, an important question remained whether the supraliminal primes could similarly influence the SoA for free versus instructed actions.

In the current study thus, we examined the influence of freedom and fluency in action selection on the SoA. We used supraliminal action primes and participants performed either instructed or freely chosen actions. Accordingly, the action primes consisted of photos of a human hand performing one of two actions (i.e., lifting either the index or the middle finger). Importantly, due to the nature of these primes, the presentation of them was considered akin to the scenario in which participants would observe someone else performing an action. Correspondingly, one of the most influential findings regarding the human motor system is that a specific neural network, namely the parietal premotor network, is activated not only when one performs an action but also when one passively observes others perform the same action (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). This finding has lead to the development of several behavioral and neuroimaging paradigms to investigate the function of this *mirroring* system in, specifically, social contexts. One such paradigm is called the automatic imitation paradigm (Heyes, 2011) in which participants perform speeded movements in response to the cues presented together with action images on the screen. Importantly, participants' responses can be either congruent or incongruent with these actions and the critical finding is that responses to the cues are slower and more erroneous when these cue require incongruent than congruent movements (Brass, Bekkering, & Prinz, 2001; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Obhi, Hogeveen, & Pascual-Leone, 2011; Obhi & Hogeveen, 2013). This interference effect is suggested to be driven by suppressing the automatic activation of the corresponding motor representations of the observed actions.

Taken together, the action primes used in the current study were thus considered to activate the corresponding action representations when participants viewed these primes. Importantly, participants had to maintain these action primes until a color cue appeared on the screen requiring participants to make speeded finger lift (index or middle) in relation to both the action primes and the color of the cues. More specifically, a white cue indicated that participants could freely choose which finger to lift regardless of the preceding prime, which was either neutral (neutral-free selection) or an action image (primed-free selection). If the cue was green, however, participants had to perform the same finger lift as in the prime (prime-compatible selection) and finally, a red cue instructed to lift the alternative finger that was not lifted in the action prime (prime-incompatible selection). Therefore, the compatibility between the automatic activation of the motor representations in response to the primes and the required responses indicated by the target cues were presumed to alter the degree of effort in action selection. This enabled us to examine the effect of selection fluency on both intentional binding and subjective judgments of agency, which has never been examined in one experimental setting. Moreover, obtaining these two measures of the SoA could also allow investigating the relationship between them.

Accordingly, perceived action-outcome intervals and FoC judgments were obtained in two separate experiments in order to avoid any contamination between these two measures. In contrast to the previous studies in which action-outcomes were mapped to actions (e.g., Chambon & Haggard, 2012; Sidarus et al., 2013; Wenke et al., 2010), actions in our study produced the same tone throughout the experiment. This was to keep the focus of the study purely on the effects of action selection processes. Moreover, we obtained a subjective measure of perceived mental effort in a short task at the end of both interval estimation and FoC rating tasks. As such, we could examine differences in perceived effort across the experimental conditions.

We predicted that the neutral-free condition would be perceived as the least effortful as this condition does not require the maintenance of any action due to the neutral prime. Also, the prime-incompatible condition was predicted to be rated as the most effortful since the actions represented in the primes had to be maintained and then updated to give the prime-incompatible response. Our prediction about perceived effort in the primed-free condition was twofold. If participants tended to disregard the prime and perform prime-incompatible actions, we predicted that this condition could be perceived as more effortful compared to the prime-compatible condition. If, on the other hand, participants tend to choose the prime-compatible action more frequently then the primed-free and the prime-compatible conditions would be perceived at similar effort levels.

Given that previous studies proposed that action selection fluency is a prominent factor affecting the SoA, we would predict that the conditions in which action selection is more fluent (i.e., less effortful, Chambon et al., 2014; Demanet, Muhle-Karbe, Lynn, Blotenberg, & Brass, 2013) could yield shorter estimations of action-outcome intervals and higher FoC ratings compared to those taking more effort to select an action. More specifically, we at least expected to find that binding and FoC would be strongest in the neutral-free condition while the prime-incompatible condition-presumably the most effortful one- would lead to the weakest binding and FoC. The primed-free condition per se is closely relevant to Damen et. al's study in which supraliminal primes were always followed by free selection of actions. In this condition thus, we would predict to find similar results with weaker SoA with compatible than incompatible free actions. However, since this is the only study we can refer to as employing supraliminal priming, this prediction does not have a strong basis. Regarding the prime-compatible condition, our prediction again was based on the previously noted relationship between selection fluency and the SoA. More clearly, we predicted that binding and FoC would be stronger compared to the prime-incompatible condition while being weaker than, at least, neutral-free condition.

6.3 Method

6.3.1 Participants

In total, we recruited 54 participants who were undergraduate students at Wilfrid Laurier University. 28 participants were assigned to the interval estimation task (6 male, 2 left-handed, M_{age} = 18.32, *SD*= 1.42) while the remaining 26 participants completed the FoC rating task (4 male, 1 left-handed, M_{age} = 18.88, *SD*= 1.53). 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. The compensation for participating in the study was course credits.

6.3.2 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: 1600x1200). Action primes consisted of pictures of a hand lifting either the index or the middle finger (see Figure 6.1). These images were placed in a rectangle with a black border (size: 3.13” x 4.69”) and the neutral prime was the blank version of the same rectangle. Presentation of all stimuli was centered on a white background. Responses were made on a standard keyboard. An optical wheel mouse was used to indicate responses on visual analogue scales presented on the screen for interval estimation, FoC rating, and effort rating tasks.

6.3.3 Procedure

First 28 participants completed the interval estimation task while the remaining 26 participants were assigned to the FoC rating task. At the beginning of each task, participants were explained the task requirements and and shown the stimuli, and they completed 10 practice trials. The practice session was repeated when the experimenter observed failure in understanding the instructions (e.g., responses being slower than 2 s or too many erroneous trials). Each interval estimation and FoC rating task consisted of 360 trials and was followed by a 24-trial effort rating task.

Each trial began with the warning signal “New trial, get ready!” which remained on the screen for 1 s. The warning signal required the participants to press and hold down both “b” and “v” keys by their left index and middle fingers, respectively. This was followed by the fixation cross (500 ms) and then the prime image (500 ms) which could be either an action or a neutral prime (i.e., a blank rectangle). The target cue (a colored circle) was presented after a 150 ms following the prime. In response to the target cue, participants were told to respond as fast as possible by releasing either their index or middle finger off the corresponding key. Which key they would release depended on the color of the target cue. Accordingly, a green circle indicated that they should release the same finger as was lifted in the action prime (prime-compatible response), a red circle indicated that they should release the finger that was not lifted in the prime (prime-incompatible response). Finally, a white circle indicated that participants could make their own selection of releasing either the index or the middle finger. The free response condition included trials in which the target screen was preceded by either an action prime (primed-free response) or a neutral prime (neutral-free response). In either case, participants were instructed to make their own choice and not to give stereotyped responses. Each key release produced a short beep sound (1000 Hz, bit rate: 160 Kbps) after one of three different delays (100 ms, 300 ms, 500 ms). However, participants were told that for each trial, this delay was randomly picked within the range of 1 ms to 1000 ms (1 s). The target cue remained on the screen until the tone was presented. At the end of each trial in the interval estimation task, they were asked to estimate the delay on a visual analogue scale which was marked at 50 ms intervals. To do so, they used the mouse with their right hand and moved the cursor to the point where they thought would correspond to their estimation. They were informed that they could click on any point on the scale including the values between two markers. No prior training was given for interval estimations. Inter-trial interval was set to 500 ms during which a blank screen was presented.

The trials in the FoC rating task were exactly the same except that at the end of each trial, participants rated on 6-point visual analogue scale (1: low, 6: high) to indicate their subjective FoC over the production of the tone. They were encouraged to avoid basing their judgments on how fast or correct they respond in releasing the keys (see Figure 6.1).

The combination of action selection mode (prime-compatible, prime-incompatible, primed-free response, unprimed-free response) and delay (100 ms, 300 ms, 500 ms) levels were presented in a mixed and random order. Upon completion of each 48 trials, the experiment paused for the participants to take a break if they needed. After each break, participants pressed the space bar to continue and the next block of 48 trials started after the presentation of a reminder that noted the color-response mapping and the requirement of responses to be as fast and accurate as possible.

At the end of each task, participants completed another 24 trials in which they instead reported how (mentally) effortful it was for them to choose which finger to lift. They again used a 6-point visual analogue scale (1: low, 6: high) to indicate their perceived effort in each trial. In total thus, participants completed 384 trials in each of interval estimation and FoC rating tasks. For each trial in the experiment, response times (RTs) to release the key and responses on the interval estimation, FoC, and effort rating scales were recorded. At the end of the experiment, participants were debriefed and thanked for their time.

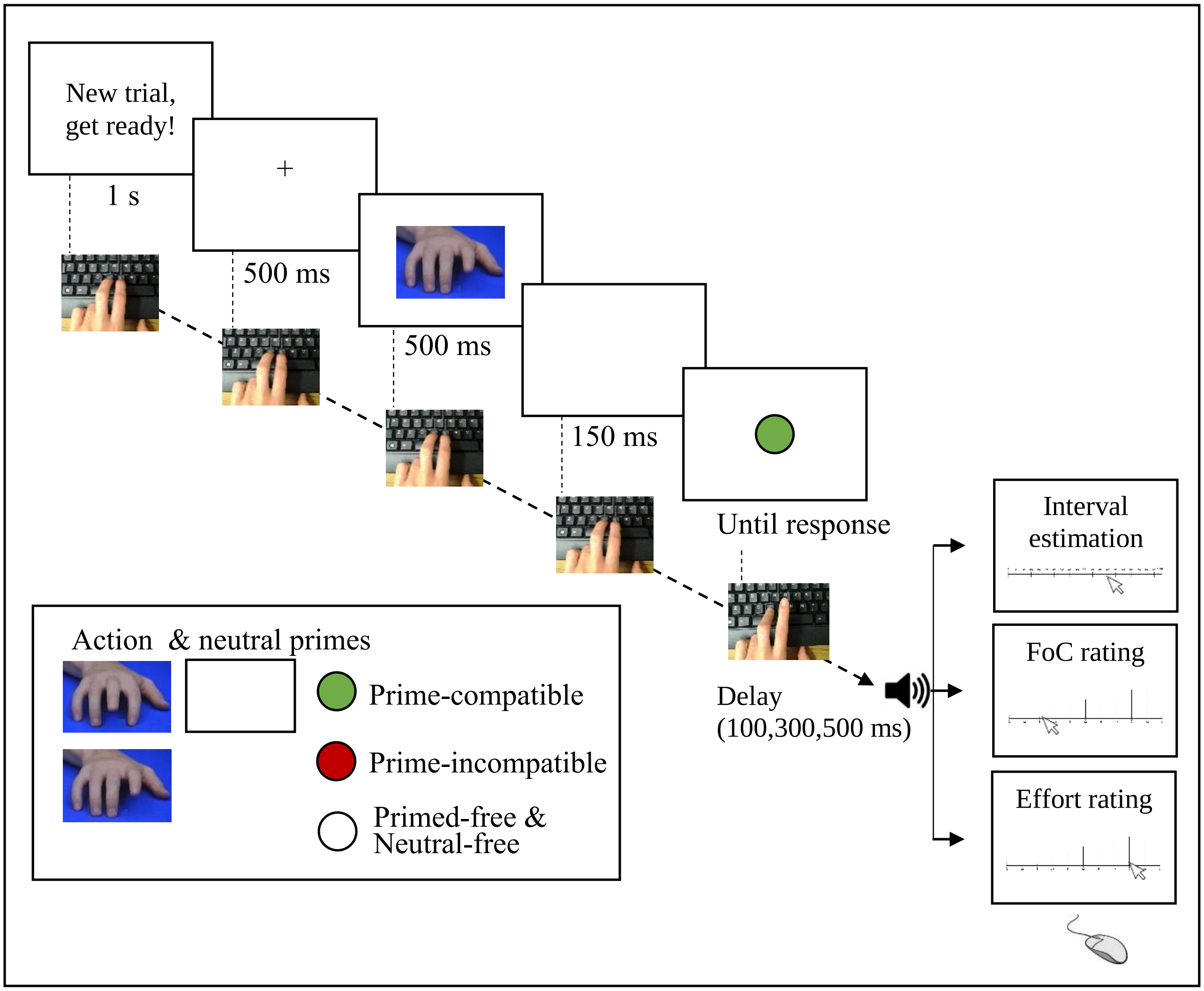


Figure 6.1 Illustration of the procedure in the interval estimation and FoC rating tasks. Participants performed either free, prime-compatible, or prime-incompatible key releases which produced a tone. In the interval estimation task, they estimated the delay between the key release and the tone while in the FoC rating task they rated their subjective FoC over the tone. Both tasks were followed by the effort rating task in which participants rated how effortful it was to choose which key to release.

6.3.4 Data analysis

For the interval estimation task, trials with RTs or interval estimations being three standard deviations away from the mean, and those with incorrect key release responses were excluded ($M_{excluded}$ = 6.24%, *SD*= 3.63% of all trials). Participant exclusion criteria dismissed the data of participants who had more than 20% of all trials excluded or failed to demonstrate a monotonic increase in estimating the delay across 100 ms, 300 ms, and 500 ms. The latter criterion resulted in the exclusion of two participants and thus the analyses of interval estimation task included twenty-six participants (5 male, 1 left-handed, M_{age} = 18.38, *SD*= 1.55).

For the control rating task, trials with RT being three standard deviations away from the mean and those with inaccurate responses were excluded ($M_{excluded}$ = 5.40%, *SD*= 4.22% of all trials). Similarly, participant exclusion criterion was concerned with those having the trial exclusion rate greater than 20% of all trials.

We used repeated measures analysis of variance (ANOVA) to examine the effects of selection mode and action-outcome delay on accuracy, response times (RTs), interval estimations, FoC ratings, and perceived effort ratings. Data analyses for accuracy, RTs, and effort ratings were conducted across data from both tasks while the SoA measures were examined separately for each task. *Post hoc* multiple comparisons (Bonferroni corrected) were performed where differences across variable levels were examined. Additionally, two-tailed paired samples t-tests and one sample t-tests were conducted where appropriate. For each participant, we performed separate Pearson's correlation analyses in order to examine the relationship between perceived intervals and RTs, effort ratings and RTs, and FoC ratings and RTs for each action selection mode. The correlation coefficients were then subjected to t-tests for the analyses across participants. The relationship among the remaining variables, i.e., perceived intervals, FoC ratings, and effort ratings, were analyzed subjecting participants' means to Pearson's correlation analyses. All data analyses were conducted using SPSS (version 16.0) and the significance level was set to .05.

6.4 Results

6.4.1 Accuracy

Before excluding incorrect trials from further analysis, we examined the differences in accuracy between prime-compatible and prime-incompatible conditions. Mean accuracy in the prime-compatible condition (lifting the same finger as in the action prime) and in the prime-incompatible condition (lifting the finger that is resting in the prime) were 90 % (*SD*=.73) and 90% (±.82), respectively. We conducted a 2 x 2 repeated measure ANOVA with selection mode (prime-compatible, prime-incompatible) as within subjects factor and task (interval estimation, FoC rating) as between subjects factor. The test revealed neither a significant effect of selection mode ($F<.1$, $p>.7$) nor a significant interaction between selection and task ($F<.1$, $p>.8$).

6.4.2 Response times

Mean RTs for each selection mode displayed a gradual increase in the order of neutral-free (*M*=356.39, *SD*=166.88), prime-compatible (*M*=548.83, *SD*=77.84), primed-free (*M*=570.66, *SD*=89.60), and prime-incompatible conditions (*M*=581.18, *SD*=82.08). RTs were subjected to a 4 x 2 x 2 repeated measures ANOVA with selection mode (neutral-free, primed-free, prime-compatible, prime-incompatible) and released-finger (index, middle) as within subjects factors and task (interval estimation, FoC rating) as between subjects factor. The test revealed a significant main effect of selection ($F(3,150) = 101.70$, $p<.001$, $\eta^2 = .67$) and a significant interaction between selection and finger

($F(3,150) = 17.26$, $p<.001$, $\eta^2 = .26$). The main effect of finger was not significant ($p>.4$) and there was no significant interaction with task ($p>.8$). *Post hoc* multiple comparisons for selection modes showed that RT in the neutral-free condition was significantly faster compared to all other conditions (all *ps*<.001) and RT in the prime-compatible condition was faster compared to both primed-free ($p=.004$) and prime-incompatible ($p<.001$) conditions. The difference between primed-free and prime-incompatible conditions was not significant ($p>.1$). In order to resolve the two-way interaction between selection mode and finger, we performed Bonferroni corrected paired samples t-tests to compare the differences between index and middle finger responses at each level of selection mode. The tests revealed that when participants performed prime-compatible actions, they responded faster when releasing index (M=532.94, SD=72.43) compared to middle finger (M=567.70, SD=83.26); $t(51)$= -5.61, $p<.001$. In contrast, releasing the index finger (M=602.47, SD=84.92) in the prime-incompatible condition was significantly slower than releasing the middle finger (M=559.88, SD=79.23); $t(51)$= 7.17, $p<.001$. The differences between releasing index and middle fingers in the neutral-free and primed-free conditions were not significant (*ps*>.4; see Figure 6.2).

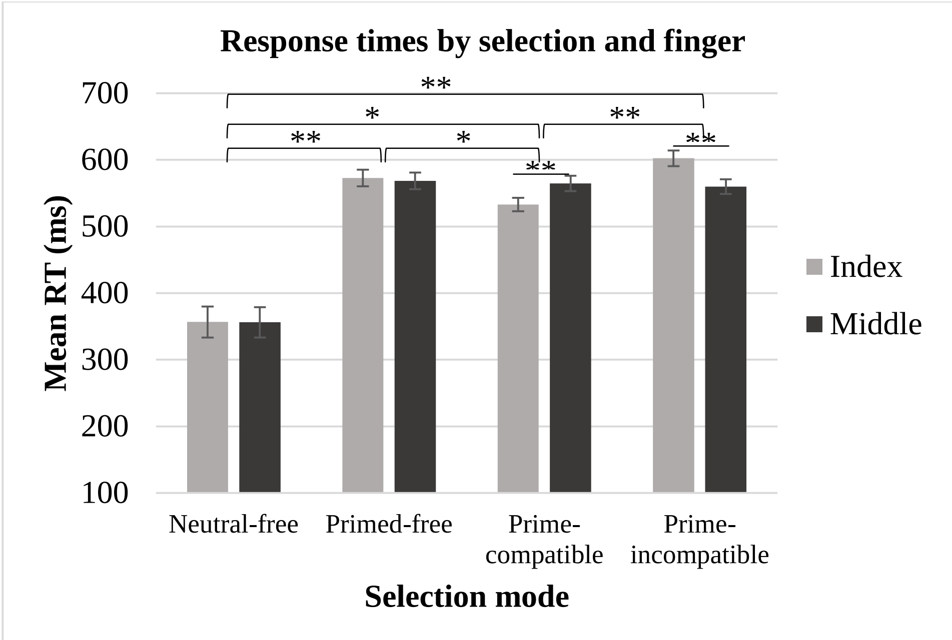


Figure 6.2 Mean RTs as a function of selection mode and released finger. Error bars represent *SEM* (*p<.05, **p<001).

6.4.3 Perceived effort

Mean effort ratings showed that participants perceived the key release selection in the prime-incompatible condition to be more effortful (M=3.68, SD=1.17) compared to prime-compatible (M=2.82, SD=.95), primed-free (M=2.52, SD=.95), and neutral-free (M=1.86, SD=.90) conditions. We analyzed the effort ratings by a 4 x 2 repeated measures ANOVA with selection mode (neutral-free, primed-free, prime-compatible, prime-incompatible) as the within subjects factor[4] and task (interval estimation, FoC rating) as the between subjects factor. The test revealed a significant main effect of selection mode (F(3,150) = 62.95, p<.001, η^2 = .56). There was no interaction with task

[4] As a 4 x 2 ANOVA with selection mode and released-finger did not reveal any significant effects of or interactions with released-finger, we collapsed the finger levels.

(p>.7). *Post hoc* multiple comparisons showed that the neutral-free condition was perceived significantly less effortful compared to the primed-free (p<.001), prime-compatible (p<.001), and prime-incompatible (p<.001) conditions. Similarly, the primed-free condition was perceived as significantly less effortful compared to both the prime-compatible (p=.014) and prime-incompatible (p<.001) conditions. Finally, the prime-compatible condition was reported to be significantly less effortful than prime-incompatible condition (p<.001; see Figure 6.3).

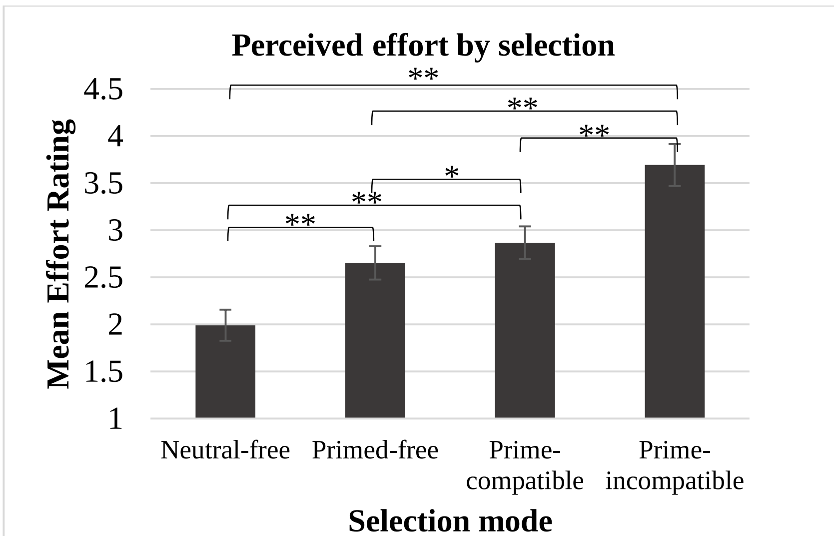


Figure 6.3 Mean effort ratings in each selection condition. Error bars represent *SEM*. (*p<.05, **p<001).

6.4.4 The SoA measures

6.4.4.1 *Interval estimations*

Mean interval estimations for each actual delay demonstrated a monotonic increase across 100 ms (M=253.08, SD=134.25), 300 ms (M=414.82, SD=125.82), and 500 ms (M=569.89, SD=172.04). Regarding the selection mode, participants perceived the key release-tone delay to be shorter in the neutral-free condition (M=385.22, SD=135.69) compared to prime-compatible (*M*=417.59, *SD*=148.17), primed-free (*M*=419.51, *SD*=144.34), and prime-incompatible (*M*=428.07, *SD*=147.96) conditions. In order to examine the effects of selection mode and actual delay on the perceived intervals, we conducted a 4 x 3 repeated measures ANOVA[5] with selection mode (neutral-free, primed-free, prime-compatible, prime-incompatible) and delay (100 ms, 300 ms, 500 ms) as within subject factors. The test revealed significant main effects of selection mode ($F(3,75) = 7.79$, $p<.001$, $\eta^2 = .24$) and delay ($F(2,50) = 62.91$, $p<.001$, $\eta^2 = .72$), and a significant interaction between selection mode and delay ($F(6,150) = 5.54$, $p<.001$, $\eta^2 = .18$). Regarding the main effect of selection mode, *post hoc* tests showed that participants perceived the key release-tone delay in the neutral-free condition to be significantly shorter compared to primed-free ($p=.037$), prime-compatible ($p=.014$), and prime-incompatible ($p=.022$) conditions (see Figures 6.4 and 6.5). None of the remaining differences were significant (all *p*s>.8). Examination of the perceived differences among the delay levels were found to be significant at all levels (all *p*s<.001). Finally, we conducted three separate one-way repeated measures ANOVAs by selection mode for each level of delay to resolve the selection mode x delay interaction. The tests showed that the main effect of selection mode was significant at all 100 ms, 300 ms, and 500 ms levels of the key release-tone delay ($F(3,75) = 7.37$, $p<.001$, $\eta^2 = .23$; $F(3,75) = 4.88$, $p=.004$, $\eta^2 = .16$; $F(3,75) = 8.37$, $p<.001$, $\eta^2 = .25$, respectively). However, multiple comparison tests to further examine the differences across selection modes at each delay

[5] Factoring in released-finger did not reveal any significant effects and thus we reported the results of a 4 x 3 ANOVA.

yielded mixed results. At 100 ms, the difference in the perceived intervals between neutral-free (*M*=230.36, *SD*=114.52) and primed-free (*M*=276.17, *SD*=145.13, $p=.007$) conditions and between primed-free and prime-compatible (*M*=247.39, *SD*=131.27, $p<.001$) conditions were significant. All other differences failed to reach significance (all *p*s>.2). At 300 ms, perceived interval in the neutral-free condition (*M*=388.60, *SD*=115.17) was significantly shorter than both primed-free (*M*=424.94, *SD*=126.51, $p=.047$) and prime-incompatible (*M*=430.44, *SD*=130.09, $p=.042$) conditions (all *p*s>.3 for the remaining differences). At 500 ms, perceived interval was significantly shorter in the neutral-free (*M*=536.69, *SD*=177.38) condition compared to prime-compatible (*M*=590.07, *SD*=181.71, $p=.002$) and prime-incompatible (*M*=595.38, *SD*=167.69, $p=.022$) conditions. Additionally, perceived interval in the primed-free condition (*M*=557.42, *SD*=161.36) was significantly shorter than both prime-compatible ($p=.035$) and prime-incompatible conditions ($p=.005$). The remaining comparisons did not reveal any significant differences (all *p*s>.05).

Overall, the analyses of perceived intervals between key releases and tones suggest that the size of temporal attraction and by extension, the strength of the SoA was greatest in the neutral-free condition in which participants were free to choose which key to release without being influenced by the action primes.

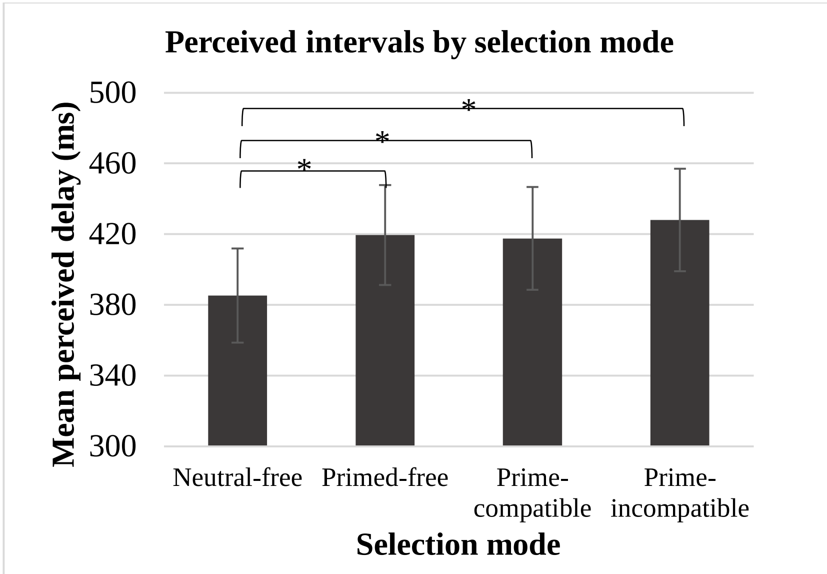


Figure 6.4 Mean perceived action-outcome intervals in the interval estimation task for each selection condition. Error bars represent *SEM* (**p*<.05).

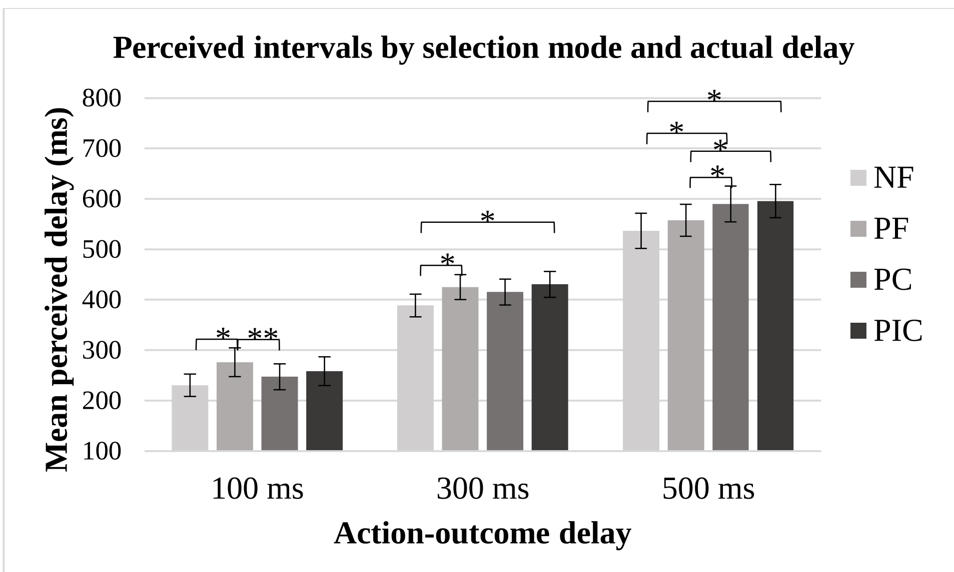


Figure 6.5 Mean perceived action-outcome intervals in the interval estimation task for each selection and actual delay condition. Error bars represent *SEM* (**p*<.05, ***p*<.001).

6.4.4.2 *FoC ratings*

We calculated the mean FoC ratings for each delay and selection mode (see Figures 6 and 7). Accordingly, participants reported stronger FoC over the tone when the key release-tone delay was 100 ms (*M*=4.97, *SD*=.59) compared to when it was 300 ms (*M*=4.52, *SD*=.77) and 500 ms (*M*=4.08, *SD*=1.15). Regarding the selection mode, mean FoC rating was reduced in the order of neutral-free (*M*=4.76, *SD*=.85), prime-compatible (*M*=4.51, *SD*=.81), primed-free (*M*=4.47, *SD*=.77), and prime-incompatible (*M*=4.34, *SD*=.92) conditions. In order to examine the effects of selection mode and actual delay on the FoC ratings, we conducted a 4 x 3 repeated measures ANOVA with selection mode (neutral-free, primed-free, prime-compatible, prime-incompatible) and delay (100 ms, 300 ms, 500 ms) as within subject factors. The test revealed significant main effects of selection mode ($F(3,75) = 7.56$, $p<.001$, $\eta^2 = .23$) and delay ($F(2,50) = 15.37$, $p<.001$, $\eta^2 = .38$), and a significant interaction between selection mode and delay ($F(6,150) = 3.41$, $p=.003$, $\eta^2 = .12$).

Post hoc tests comparing selection modes showed that participants felt significantly stronger control over the tone in the neutral-free condition compared to all primed-free ($p=.016$), prime-compatible ($p=.026$), and prime-incompatible ($p=.011$) conditions. None of the other differences was significant (all *p*s>.1). Examination of the FoC ratings across the delay levels showed that FoC rating was significantly higher when the delay was 100 ms than when it was 300 ms ($p=.005$) and 500 ms ($p=.002$). Additionally, FoC rating was significantly higher at 300 ms compared to 500 ms ($p=.001$). Finally, we performed three separate one-way repeated measures ANOVA to examine the effect of selection mode at each level of delay. The tests showed that the main effect of selection mode on FoC rating was significant at all 100 ms, 300 ms, and 500 ms levels of the key release-tone delay (F(3,75) = 3.91, p=.012, η^2 = .14; F(3,75) = 8.66, p<.001, η^2 = .26; F(3,75) = 8.37, p<.001, η^2 = .25, respectively). Multiple comparison tests to examine the differences across selection modes at each delay showed that at 100 ms, the only significant difference was between neutral-free (*M*=5.15, *SD*=.53) and primed-free (*M*=4.86, *SD*=.54, *p*=.008) conditions (all *p*s>.2 for the remaining comparisons). At 300 ms, FoC rating was significantly higher in the neutral-free condition (*M*=4.79, *SD*=.80) than all primed-free (*M*=4.49, *SD*=.72, *p*=.022), prime-compatible (*M*=4.49, *SD*=.73, *p*=.017), and prime-incompatible (*M*=4.29, *SD*=.84, *p*=.004) conditions (all *p*s>.09 for the remaining comparisons). Finally, at 500 ms, FoC rating was significantly higher in the neutral-free (*M*=4.34, *SD*=1.21) compared to prime-compatible (*M*=4.04, *SD*=1.15, *p*=.007) and prime-incompatible (*M*=3.87, *SD*=1.18, *p*=.002) conditions (all *p*s>.07 for the remaining comparisons).

To summarize, the influence of selection mode on the FoC ratings was in the same direction as on the perceived intervals. That is, participants experienced stronger FoC over the tones when they freely chose which key to release in the neutral-free condition.

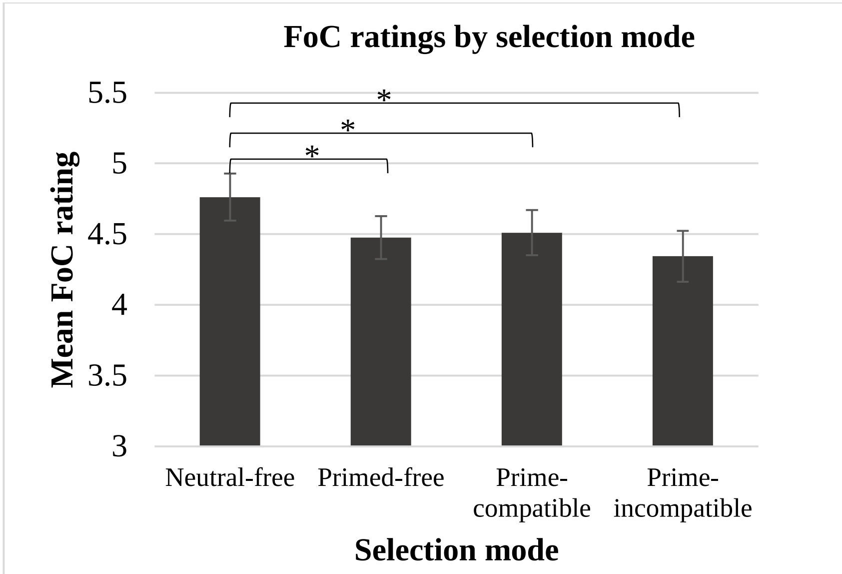


Figure 6.6 Mean FoC ratings for each selection mode. Error bars represent *SEM* (**p*<.05).

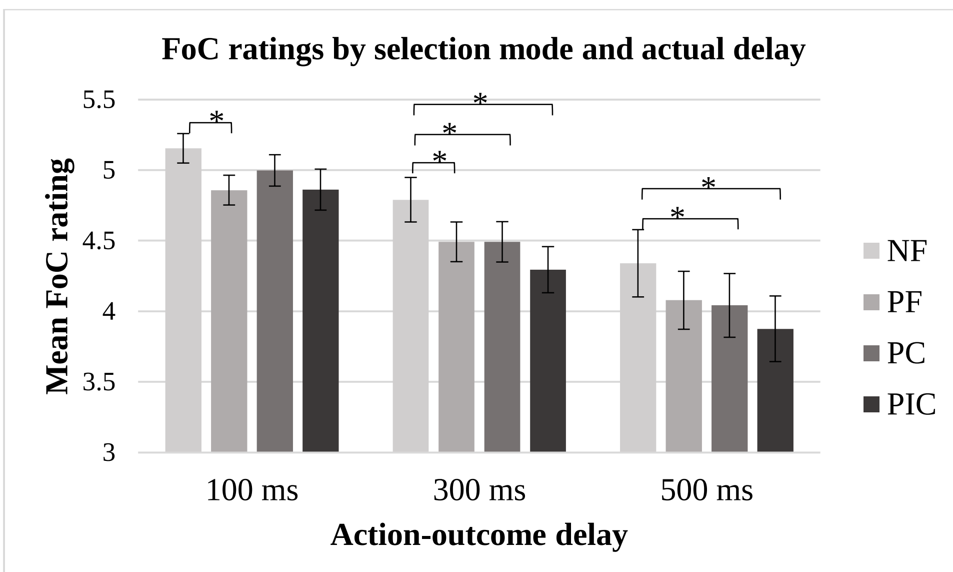


Figure 6.7 Mean FoC ratings for each selection and actual delay condition (NF: neutral-free; PF: primed-free; PC: prime-compatible; PIC: prime-incompatible). Error bars represent *SEM* (**p*<.05).

6.4.5 Action selection in free conditions

In the neutral-free condition, participants chose the index finger at a ratio of 55.89% (*SD*=20.76%), which was greater than chance level ($t(51)=19.42$, $p<.001$). We also examined whether the action primes in the primed-free condition biased participant's selection of key release. We thus conducted a one sample t-test and found that the ratio of selecting the prime-compatible finger release (*M*=63.39%, *SD*=21.13%) was significantly greater than the chance level, $t(51)=21.63$, $p<.001$.

6.4.6 Correlation analyses

6.4.6.1 *RTs and effort ratings*

For each participant, we performed Pearson's correlation analyses to examine the relationship between RTs and effort ratings under each selection mode (neutral-free, primed-free, prime-compatible, prime-incompatible). Twenty-five participants out of fifty-two showed significant correlations between RTs and effort ratings in at least one condition. Mean Pearson correlations were 0.21, 0.30, 0.28, and 0.42 in the neutral-free, primed-free, prime-compatible, and prime-incompatible conditions, respectively. The overall correlation coefficient calculated by collapsing the action selection conditions was .48. We conducted two-tailed t-tests to examine the significance of the r values and found that in all but neutral-free condition, RTs and effort ratings were significantly correlated (neutral-free: $t(51)=1.52$, $p=.135$; primed-free: $t(51)=2.22$, $p=.030$; prime-compatible: $t(51)=2.06$, $p=.044$; prime-incompatible: $t(51)=3.27$, $p=.001$; overall: $t(51)=3.87$, $p<.001$). The relationship between RTs and effort ratings suggests that for each selection mode except the neutral-free condition, effort ratings were increased as it took the participants longer to respond (see Figure 6.8).

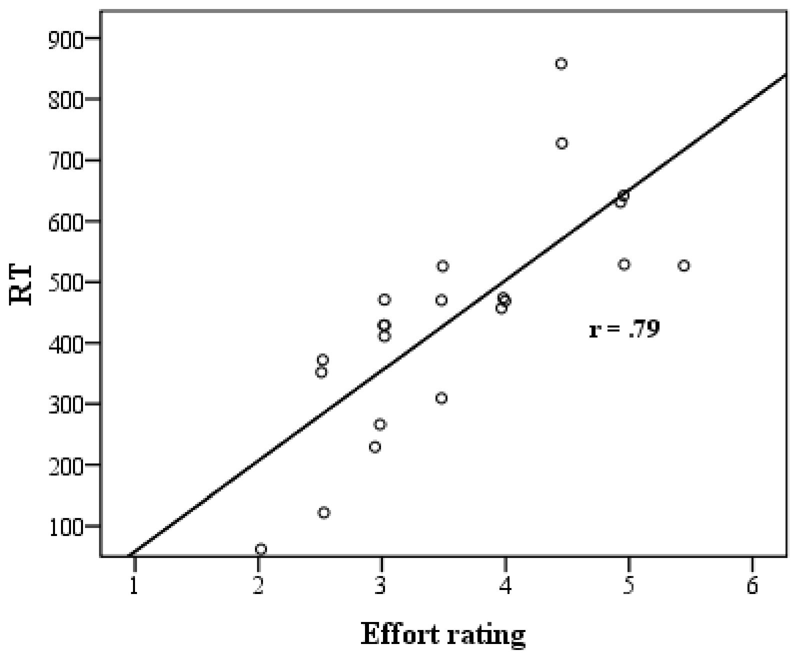


Figure 6.8. Overall correlation between RTs and effort ratings demonstrated for one participant.

6.4.6.2 *RTs and perceived intervals*

In the interval estimation task, fifteen participants out of twenty-six showed significant correlations between perceived intervals and RTs for at least one selection mode. On average, the variance in the perceived intervals accounted by RTs was 0.14 in the neutral-free, 0.15 in the primed-free, 0.10 in the prime-compatible, and 0.15 in the prime-incompatible condition. Overall correlation coefficient was .13. We performed t-tests on these values and found that none of the correlations was significantly greater than zero. (neutral-free: $t(25)=.69$, $p=.495$; primed-free: $t(25)=.74$, $p=.464$; prime-compatible: $t(25)=.49$, $p=.627$; prime-incompatible: $t(25)=.74$, $p=.464$; overall: $t(25)=.64$, $p=.526$).

6.4.6.3 *Effort ratings and perceived intervals*

In the interval estimation task, we analyzed the relationship between perceived intervals and effort ratings across participants[6] for each selection mode and found a significant correlation in the prime-incompatible condition (r=.54, p=.005; see Figure 6.9). Pearson's correlations in the neutral-free (r=.17, p=.401), primed-free (r=.15, p=.456), and prime-compatible (r=.28, p=.168) were not significant. We also examined the overall correlation between effort ratings and perceived intervals and found a positive correlation approaching the significance level (r=.36, p=.074). The relationship between perceived intervals and effort ratings therefore suggests that perceived intervals were longer as the perceived effort was greater, which was more strongly pronounced in the prime-incompatible condition.

[6] As the number of trials in the effort rating task was not equal to those in each condition in the interval estimation/FoC rating tasks, we could not perform within subject correlations.

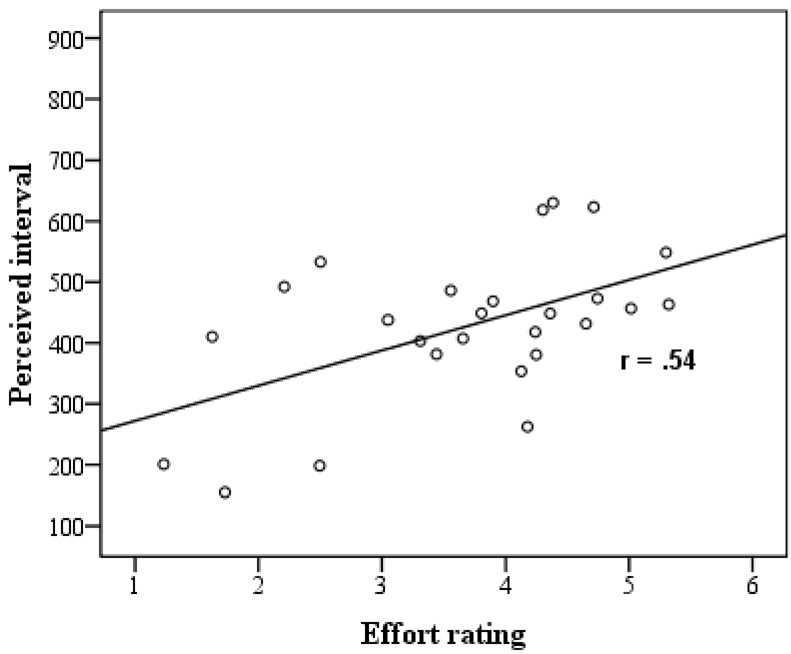


Figure 6.9. Between subjects correlation between perceived intervals and effort ratings in the prime-incompatible condition.

6.4.6.4 *RTs and FoC ratings*

In the FoC rating task, seventeen participants out of twenty-six showed significant correlations between FoC ratings and RTs in at least one condition. Average correlations were -0.19 in the neutral-free, -0.05 in the primed-free, -0.12 in the prime-compatible, and -0.20 in the prime-incompatible condition. Overall correlation coefficient was -.16. Pearson correlations were then subjected to t-tests which showed that none of these correlations was significant (neutral-free: $t(25)=-.94$, $p=.352$; primed-free: $t(25)=-.24$, $p=.808$; prime-compatible: $t(25)=-.59$, $p=.559$; prime-compatible: $t(25)=-1$, $p=.327$; overall: $t(25)=-.79$, $p=.435$). The lack of a significant correlation between RTs and FoC ratings suggest that participants did not make their FoC judgments based on their response performance.

6.4.6.5 *Effort ratings and FoC ratings*

We also examined the correlations (across participants[6]) between FoC ratings and effort ratings for each selection mode and found a significant correlation in the prime-incompatible condition (r=-.41, p=.035; see Figure 6.10). Correlations in the neutral-free (r=-.15, p=.460), primed-free (r=.07, p=.739), and prime-compatible (r=-.35, p=.077) as well as overall correlation (r=-.21, p=.303) between effort ratings and FoC ratings were not significant. In the prime-incompatible condition thus, participants reported to have less control over the tone as they perceived it more effortful to choose which key to release.

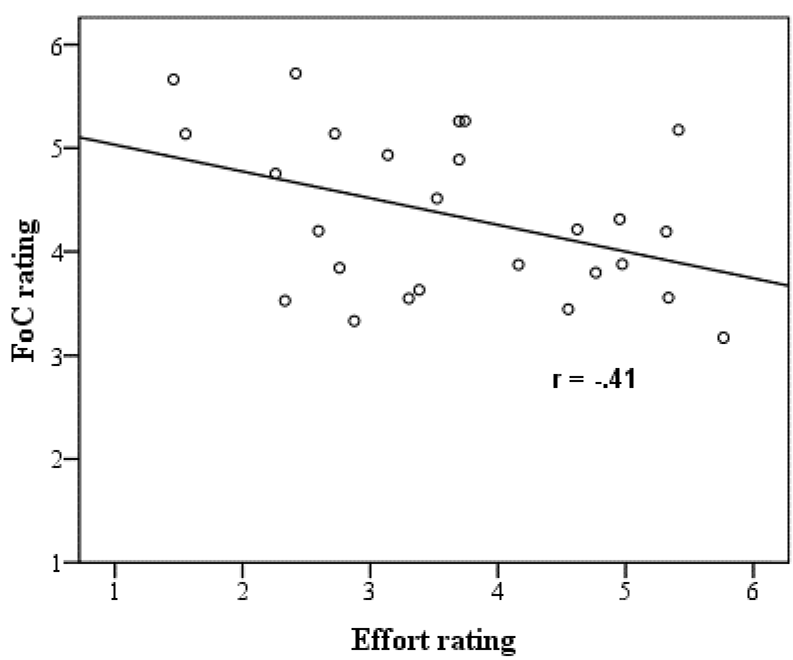


Figure 6.10. Between subjects correlation between FoC ratings and effort ratings in the prime-incompatible condition.

6.4.6.6 *Perceived intervals and FoC ratings*

The last correlation analyses involved the examination of the relationship between the low (interval estimation) and high (FoC ratings) levels of the SoA. Matching the two groups of participants, we conducted Pearson's correlation tests on the perceived intervals and FoC ratings for each selection mode. Accordingly, the tests revealed significant negative correlations in the neutral-free (r=-.40, p=.041), primed-free (r=-.58, p=.002), prime-compatible (r=-.57, p=.003), and prime-incompatible (r=-.51, p=.008) conditions. Additionally, overall correlation between perceived intervals and FoC ratings was found to be significant (r=-.57, p=.002). Since briefer perception of delays imply a stronger intentional binding effect (Haggard et al., 2002), negative correlations between perceived intervals and FoC ratings entail a positive relationship between these two levels of the SoA (see Figure 6.11).

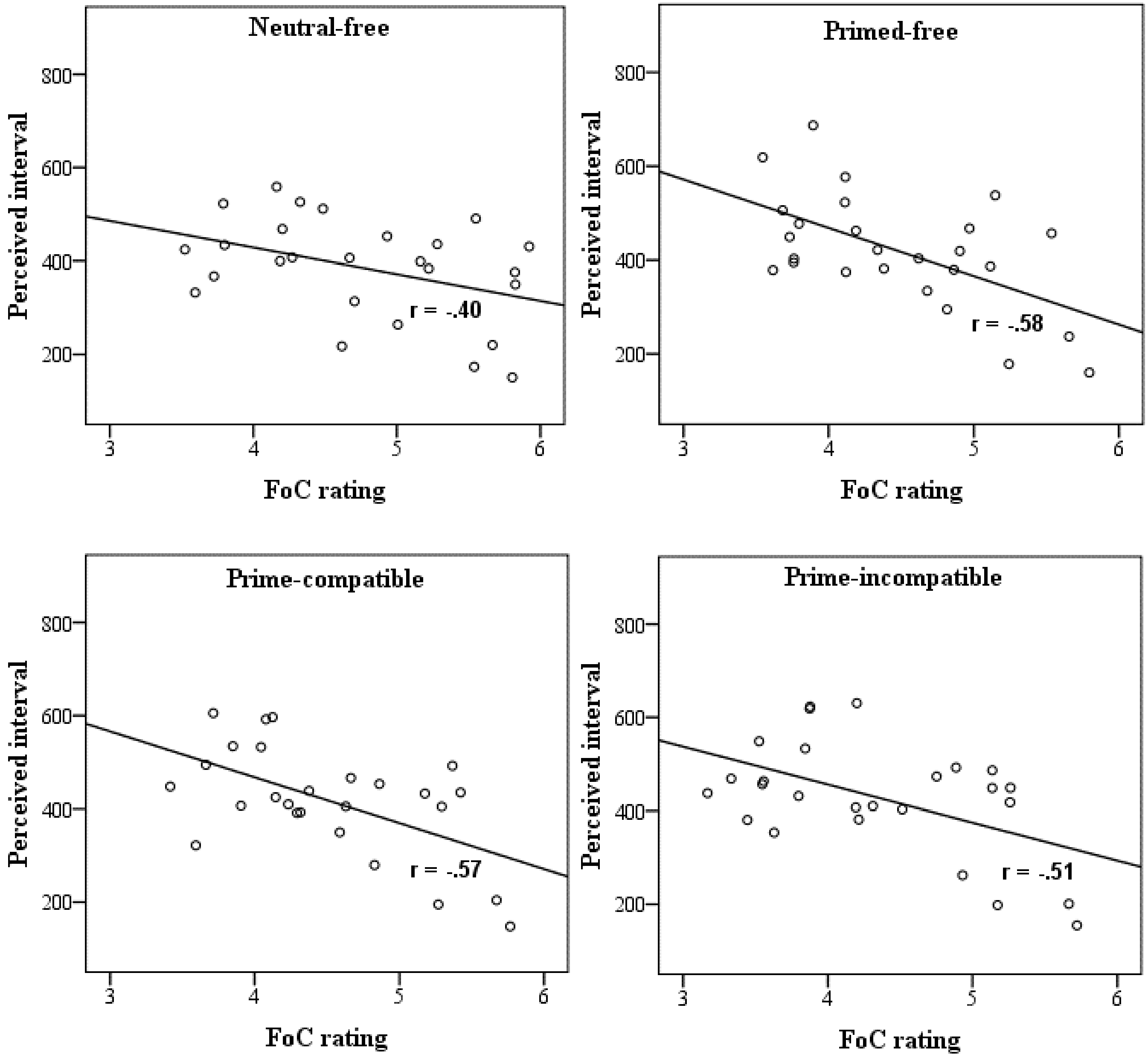


Figure 6.11. Between groups correlations between perceived intervals and FoC ratings in the neutral-free, primed-free, prime-compatible, and prime-incompatible conditions.

6.5 Discussion

Previous research has shown that subliminal priming of actions leads to enhancement in the feeling of control (FoC) judgments when these primes are compatible with the performed actions (Chambon et al., 2013; Sidarus et al., 2013; Wenke et al., 2010). This finding is commonly interpreted as being driven by the facilitation of action selection processes when action primes are compatible with the performed actions compared to when they are incompatible (Chambon & Haggard, 2012; Wenke et al., 2010). In the current study, we examined the influence of *supraliminal* priming of actions and one's freedom in action selection on both implicit and direct measures of the SoA. Our design included four different modes of action selection which were determined by a *post* prime target cue. Based on the target cue and the preceding prime, participants performed either free or instructed actions which consisted of releasing either the index or the middle finger off the corresponding keys. Free conditions included neutral (neutral-free) and action primes (primed-free) while instructed conditions required the participants to perform either prime-compatible or –incompatible actions. All actions produced a tone and we measured temporal estimation of action-outcome intervals and subjective FoC judgments as the measures of the SoA, as well as RTs and perceived effort ratings.

To begin with, examination of the subjective mental effort ratings across the modes of action selection revealed that participants' perception of effort level was highest in the prime-incompatible condition, followed by prime-compatible, primed-free, and neutral-free conditions. Although previous studies have considered incompatible action primes to be more effortful compared to compatible ones, no study thus far obtained a subjective measure of mental effort in action selection. We suggest that the differences we found in perceived effort levels among four modes of selection were due to the varying mental load and processing involved across these conditions. Except for the neutral-free condition, for instance, all other conditions required at least the maintenance of the action representations induced by the action primes. In the primed-free condition, interestingly, participants perceived more effort compared to the neutral-free condition even though they were free to choose their own action. The difference between these two conditions suggest that although one is free in selection their action, being exposed to a prior action thought and maintaining it could make it more effortful to make a self-selection. Our further examination of the primed-free condition showed that participants chose to perform the prime-compatible action more frequently, indicating a strong bias driven by the primes. However, they also reported this condition as less effortful than the prime-compatible condition in which they simply performed the same movement observed in the action prime. It could therefore be reasonable to suggest that being free to choose one's action, even under the influence of an externally induced action selection, was perceived as less effortful compared to having to perform exactly the same action as instructed. If the mental processing load can be considered as a strong factor that leads to these differences in the effort ratings (e.g., Paas, van Merriënboer, & Adam, 1994) it is not surprising that performing prime-incompatible actions was rated as the most effortful one. This condition required the participants to both maintain and update prime-induced action representations. The prime-incompatible condition thus seems to involve greater mental load to be able to select an action. In short, our results suggest that mental load and freedom to choose one's actions constitute two main factors that determine the perceived effort level in action selection. However, this interpretation should be taken with caution. In a context where there are several action alternatives as opposed only two as in the current study, one might perceive it more effortful to make a self-selection than when the selection is readily specified by an external source. Future studies could examine this possibility.

The influence of the mode of action selection was also observed on the RTs. Accordingly, slower RTs were observed in the prime-incompatible condition compared to the prime-compatible and neutral-free conditions. Additionally, participants were much faster in the neutral-free condition. Interestingly, RTs were similar in the primed-free and prime-incompatible conditions, which might be driven by the strain in making a self-selection when the presence of an external action representation is a strong biasing factor. The finding that prime-incompatible actions took longer to respond compared to prime-compatible actions is in line with the previous findings (Chambon et al., 2013; Damen et al., 2014; Sidarus et al., 2013; Wenke et al., 2010). Importantly, we also found that participants' perceived effort levels were correlated with the RTs in all except the neutral-free condition. This might suggest that RTs as the implicit indicator of effort and conscious judgments of effort denote the processing load of action selection in the same manner. That is, effort level in action selection can be indexed by both RTs and self-reports of experienced effort. One might also argue that participants might have perceived more effort when their responses were slower. However, this view requires further investigation to clarify whether perceived effort is at all mediated by RTs.

More critical to the focus of this study was the finding that the mode of action selection influenced both implicit and direct measures of the SoA. Firstly, we found that the neutral-free condition in which action selection was not influenced by external action representations led to shorter perception of the action-outcome delays compared to performing actions under the influence of such representations. As noted before, greater temporal attraction observed on perceive action-outcome delays is interpreted as a stronger binding effect and implies stronger SoA (e.g., Engbert, Wohlschläger, Thomas, & Haggard, 2007; Ku, Brass, Haggard, & Kühn, 2012; Moore & Obhi, 2012; Wenke & Haggard, 2009). Therefore, our finding that perceived intervals were at shortest in the neutral-free condition can be interpreted as showing that the low level SoA was stronger when participants were purely free to choose which action to perform without the influence of external action representations.

Crucially, the influence of action selection mode demonstrated the same trend on the FoC ratings. That is, participants reported stronger FoC over the outcomes in the neutral-free condition compared to all other conditions where an action-prime was presented. We also found that participants reported feeling less control as the action-outcome delay was increased. This is consistent with previous studies noting that action-outcome interval is a prominent retrospective cue that affects the FoC judgments (Chambon & Haggard, 2012; Chambon et al., 2013; Sidarus et al., 2013; Wenke et al., 2010). Analyses of correlations between perceived intervals and FoC ratings revealed that in all action selection conditions, perceived intervals were significantly negatively correlated with FoC ratings. Conceptually, however, the relationship between these two measures is in the same direction as longer perceived intervals indicate weaker temporal binding and hence weaker SoA. In sum, both perceived intervals and FoC ratings demonstrate that the SoA was at strongest level in the neutral-free condition. We believe that this is indeed an important finding as the relationship between low and high levels of the SoA has rarely been examined.

Regarding the relationship between effort ratings and the SoA, we found that perceived intervals were increased and the FoC ratings were decreased as the perceived effort was at higher levels. However, for both perceived intervals and FoC ratings this relationship was significant only in the prime-incompatible condition. One potential reason we failed to find a strong correlation in all action selection conditions could be due to fewer number of trials per condition in the effort rating task. This is admittedly one limitation in our study that otherwise could allow a more clear picture of the relationship between perceived effort and the SoA. It is also crucial to note at this point that we cannot put forth the measure of perceived effort as the one and only indicator of action selection fluency. There could as well be implicit processes that determine the fluency without one's awareness during action selection.

Another important finding of the current study was that neither perceived intervals nor FoC ratings were correlated with the RTs. This not only supports the previous finding that FoC ratings were independent from participants' response performance (Chambon & Haggard, 2012; Damen et al., 2014), but also shows that perceived intervals were not related to the RTs either. Thus, it does not seem likely that these measures of the SoA were somehow influenced by the response speed.

The critical question regarding these results is whether it was the least effort or the most freedom observed in the neutral-free condition that resulted in stronger SoA compared to all other modes of action selection. Although the data we report here might not be adequate to provide a far-reaching answer to this question, overall, the results of the current study enable a deeper consideration of both freedom and fluency in action selection.

There are several reasons to argue that freedom in action selection could be more influential on the SoA than selection fluency. First of all, our results showed that the SoA was indifferent across primed-free, prime-compatible, and prime-incompatible conditions although perceived effort levels among these conditions were different. In addition, except for the prime-incompatible condition, neither perceived intervals, nor FoC ratings, correlated with effort ratings. These results might strongly bear the notion that one's freedom to choose an action without any external influence can bolster the SoA. The source of such influence could be considered from two perspectives. First, as previously noted, observation of the primes could automatically mirror the actions represented in these primes (Rizzolatti et al., 1996), thereby inducing externally determined selection of action. Second, the action primes in the current study could have resembled the presence of an external agent as they represented real movements. In other words, this apparent agent was present in all but neutral-free condition. Therefore, performing either compatible or incompatible actions in relation to what an eternal agent is doing, or even being free under the influence of this agent could undermine one's SoA while there is an option to freely select an action without such an influence.

Second, the importance of freedom and internal generation of action selection have been underscored by previous research. It has been pointed out, for example, that subjective nature of freedom in action selection can be graded depending on environmental factors (Filevich et al., 2013). In the current experimental context, specifically, primed-free condition included the presence of an externally specified action, which could render this condition *less free* compared to the neutral-free condition in which internal action selection is not disturbed by external cues. Additionally, several neuroimaging studies showed that free and instructed action selections were associated with separate neural structures (Lau et al., 2004, 2006; Waszak et al., 2005) and internally generated action selections led to stronger SoA compared to externally induced action selections (e.g., Sebanz & Lackner, 2007). It reasonable, therefore, to suggest that freedom and self-generation in action selection constituted the most prominent cue influencing the SoA in the current study.

Alternatively, one might argue that the neutral-free condition led to stronger SoA because action selection was the least effort taking, and therefore much more fluent in this condition. This view, however, requires an explanation for why the SoA was indifferent among conditions which varied in the effort level. One explanation could be that intentional maintenance of action representations might introduce a ceiling effect in the influence of action fluency on the SoA. More clearly, keeping an action goal in mind until one knows which action to perform could exert the maximum effort level and later processes such as updating the action goal as in the prime-incompatible condition might not introduce a significant difference in the SoA. This might explain why SoA did not differ among prime-free, prime-compatible, and prime-incompatible conditions as all these conditions required at least the maintenance of the action primes. This is indeed one important difference in our design compared to those employed in the previous studies. That is, the task in the current study required purposeful maintenance of the action primes until a symbolic target cue (i.e., not action related), appeared to indicate whether action selection could be free or bound to the prime. Earlier studies, however, used targets that consisted of either one of the action primes and the task did not require *intentional* maintenance of the action primes (e.g., Chambon & Haggard, 2012; Damen et al., 2014; Wenke et al., 2010). Therefore, the maintenance of action primes alone could have introduced the maximum distortion to the selection fluency, which could have hindered the influence of prime-compatibility on the SoA. However, we have to admit that this view is rather speculative and needs further investigation.

We therefore conclude, for the above mentioned reasons, that our results can be best accounted by the notion of freedom in action selection. Nevertheless, further examination is required to identify how selection freedom and fluency are weighted in determining the SoA. Depending on the context, fluency or freedom could be more reliable cues to agency (Moore & Fletcher, 2012). Thus, identifying the contextual modulation of the effects of freedom and fluency is an important question for future research.

Chapter 7

General Discussion

SoA is an important aspect of self-consciousness and has significant connections to morality, taking responsibility for the consequences of one's actions, and many physiological and psychological disorders. In recent years, therefore, a vast body of research has been devoted to the investigation of the underlying mechanisms and neural correlates of the SoA. The main insight provided by the relevant research is that the phenomenology of agency is bound to several underlying processes including sensorimotor processes, interpretation of causal relationships, cognitive judgments, beliefs, and environmental factors. Among these, relatively less considered contributors of the SoA are the processes involved in action selection and the valence of action-outcomes, which are fundamental to human actions. The experiments described in thesis thus aimed at shedding light on the role of these factors on the SoA. To achieve this, five experiments were conducted to examine the influence of manipulating one's freedom to choose among a number of action alternatives and the perceived valence of action-outcomes. Importantly, the majority of these experiments used *both* indirect and direct measures of the SoA, and thereby enabled the examination of the relationship between these measures. Before presenting a comprehensive discussion on whether and how the present studies could contribute to the understanding of the SoA, the following section will summarize the key findings of five experiments (see also Table 7.1).

7.1 Summary of the key findings

In Experiment 1 (Chapter 2), the number of action alternatives was varied between one, three, and seven alternatives and the degree of intentional binding was examined across these three choice-level conditions. The results showed that the amount binding was parametrically increased as the choice space was increased from one to three to seven options. Importantly, binding size was significantly greater in the seven-choice condition compared to the one-choice condition while the three-choice condition did not differ from either the seven-choice and one-choice conditions.

Experiment 2 (Chapter 3) investigated the role of perceived pleasantness of action-outcomes on both intentional binding and the degree of subjective control felt over these outcomes. Because the auditory stimuli used in this study were characterized as pleasant or unpleasant according to western tonal structure, both western and non-western participants were recruited. The results indicated that the temporal compression between actions and outcomes was greater with pleasant than unpleasant outcomes. However, this effect was observed only in the western group of participants. Subjective ratings of control over the outcomes, on the other hand, showed that both groups experienced stronger control over pleasant than unpleasant outcomes.

In Experiment 3 (Chapter 4), participants could either freely select an action among four alternatives or perform the one that was externally specified. In addition, these actions could produce either pleasant or unpleasant outcomes. Again, both intentional binding and FoC ratings were measured. The results of this study showed that both binding and FoC ratings were greater when actions were freely selected than instructed. Additionally, pleasant outcomes led to higher FoC ratings than unpleasant outcomes, while the valence of outcomes did not influence binding. Interestingly, FoC ratings were also higher for the pleasant outcomes produced by freely selected actions than for those produced by instructed actions.

Table 7.1 Summary of the designs and main results of Experiments 1-5

Experiment	Manipulation	Outcome Identity/ Temporal prediction	Results	
			Size of binding	**FoC ratings**
#1	**1)** Choice level (one, three, and seven options)	Predicted/ Predicted	Greater in the seven-choice condition compared to the no-choice (one) condition	N/A
#2	**1)** Outcome valence (pleasant vs. unpleasant)	Predicted/ Predicted	Greater with pleasant than unpleasant outcomes (for the western group)	Greater with pleasant than unpleasant outcomes
#3	**1)** Action source (self vs. other) **2)** Outcome valence (pleasant vs. unpleasant)	Unpredicted/ Unpredicted	Greater in the free- compared to instructed-choice condition	Greater in the free- compared to instructed-choice condition and greater with pleasant than unpleasant outcomes
#4	**1)** Choice level (one, two, three, and four options **2)** Outcome valence (pleasant vs. unpleasant)	Unpredicted/ Unpredicted	Greater in the four-choice condition compared to the remaining choice-levels	Increased with choice-level and greater with pleasant than unpleasant outcomes
#5	**1)** Selection mode (neutral-free, primed-free, prime-compatible, prime-incompatible)	Predicted/ Unpredicted	Greater in the neutral-free condition compared to the remaining conditions	Greater in the neutral-free condition compared to the remaining conditions

The manipulation of choice-level was further elaborated in Experiment 4 by varying the number of action alternatives between one and four. As in Experiments 2-3, action-outcomes could be either pleasant or unpleasant, and both intentional binding and subjective FoC ratings were measured. In addition, subjective judgments of the mental effort experienced in action selection were obtained in each choice-level condition. Consistent with the main results of Experiment 1, binding of actions and outcomes was found to be systematically enhanced as the choice-level was increased from one to four options. It was significantly stronger in the four-choice condition compared to all remaining choice-levels. FoC ratings also displayed a similar trend; participants reported gradually increased FoC over the outcomes along with the increments of action options. Moreover, differences in FoC were significant at all levels of choice. With respect to the effect of outcome pleasantness, the results confirmed those found in Experiment 3. More clearly, the valence of outcomes did not influence binding while FoC ratings were higher for pleasant compared to unpleasant outcomes. Finally, participants reported experiencing significantly less effort in choosing an action in the four-choice condition compared to the remaining choice-levels.

Experiment 5 used supraliminal priming of actions and participants performed free and instructed actions in response to a target cue. The instructed actions were either compatible or incompatible actions in relation to the action-primes. In the free conditions, participants were free to perform one of two actions after being presented with either an action-prime or a neutral prime. In this study, intentional binding, FoC ratings, and subjective effort ratings were measured. The results showed that both intentional binding and subjective control were significantly stronger when participants performed free actions that were preceded by no action-prime compared to the remaining free-choice (primed) and instructed conditions. Importantly, these two measures of the SoA were significantly correlated. Finally, perceived effort in action selection was increased in the order of neutral-free, primed-free, prime-compatible, and prime-incompatible conditions.

From a broad perspective, these findings indicate that one's freedom to choose an action from a set of action alternatives has a crucial impact on the SoA. In addition to the factors related to action selection, perceived pleasantness of action-outcomes has also indispensable impact, particularly on the explicit judgments of agency. The following two sections will consider the potential mechanisms through which freedom and choice level in action selection, and the valence of action-outcomes could influence the SoA.

7.2 The role of action selection processes on the SoA

Previous research examining the role of action selection processes has mainly focused on the influence of selection fluency on the subjective reports of the SoA. This line of research has shown that subliminal priming of actions facilitated action selection when these primes were compatible with the actions, which in turn enhanced the subjective control felt over action-outcomes (Chambon et al., 2013; Sidarus et al., 2013; Wenke et al., 2010). These findings also indicated that action selection processes prospectively contribute to the SoA as these processes take place before the action is executed and are independent from the predictability of action-outcomes (e.g., Chambon et al., 2013).

The present thesis approached the study of the role of action selection processes from different perspectives. One aspect examined the SoA when, one is either free to choose among a fixed set of actions, or when one must perform an instructed action. This scenario was more directly established in Experiment 3 and Experiment 5. Both of these experiments suggested that intentional binding and subjective judgments of control were enhanced when one freely determines which action to perform relative to following the action instructions. In Experiment 3, importantly, the effect of freedom on binding was independent from the valence of the outcomes. This supports the view that processes involved in action selection, specifically one's freedom to choose an action in the context of Experiment 3, can be considered to inform the SoA prospectively (Chambon et al., 2013). Furthermore, Experiment 5 showed that freedom in action selection without any external influence (by presentation of action primes) can significantly strengthen the SoA compared to when one makes a free selection under the influence of external selection of actions. The second dimension related to the action selection processes was concerned with rendering the number of action alternatives from one to several. In this regard, Experiment 1 and Experiment 4 examined the effect of choice level on the SoA and the overall results suggested that the highest number of action alternatives boosted both intentional binding and subjective feelings of control.

Intuitively, the finding that freedom and having the highest number of choice alternatives can strongly influence the SoA is not surprising. But how exactly could these factors involve in the mechanisms contributing to the SoA, particularly to intentional binding and subjective judgments of control?

One interpretation of these results can be based on the neural correlates of free versus instructed actions and choice. Previous research suggested, for instance, that SMA is a key structure involved in internally generated action selection (Cunnington et al., 2002; Filevich et al., 2013; Lau et al., 2004, 2006; Waszak et al., 2005). Critically, this area has also been shown as a strong candidate for mediating intentional binding (Cavazzana, Penolazzi, Begliomini, & Bisiacchi, 2015; Kühn, Brass, & Haggard, 2012; Moore, Ruge, Wenke, Rothwell, & Haggard, 2010). In addition, rostral SMA and right DLPC have been found to show increased activity when two to four free-choice conditions were contrasted with instructed conditions (Van Eimeren et al., 2006).

In line with these findings indicating differences in the neural correlates of free versus instructed actions, the affordance competition hypothesis (Cisek, 2007) provides a more specific account of processing the selection of actions. This model proposes that a final selection of action is the result of preceding inhibitory and excitatory processes that dynamically operate among different action representations. The competition between these representations within fronto-parietal circuits ultimately results in inhibition of all representations except the one with strongest activation. In this view, the activation strength of the selected action's representation would increase in parallel to the number of competing representations. In other words, the greater the choice space the greater the activation of the ultimately selected action. Thus, the affordance competition hypothesis would also suggest that free selection among several action alternatives would imply stronger endogenous processing compared to having few or no options. Therefore, both neural correlates of self-generated actions, particularly SMA, and greater internal processing with higher level of choice could provide a viable explanation for stronger binding found in Experiments 1, 3-5 when selection of actions was determined freely and with the availability of maximum number of alternatives.

Similar mechanisms could also explain the enhancement of subjective agency judgments under free and high choice level conditions (Experiments 3-5). More specifically, neural correlates of subjective judgments of agency have been reported to involve several brain areas including TPJ, IPL, SMA, ACC, and the DLPFC (David, Newen, & Vogeley, 2008; Fukushima, Goto, Maeda, Kato, & Umeda, 2013; Sperduti, Delaveau, Fossati, & Nadel, 2011). The majority of these areas also engage in action monitoring and detection of discrepancies between both action alternatives and predicted and actual outcomes (Chambon et al., 2013; David et al., 2008). It would thus be reasonable to suggest that involvement of these areas in the free selection and high level of choice conditions would be stronger, and thus lead to enhancement of subjective judgments of agency. Additionally, higher level thoughts concerning one's state and degree of freedom could also be influential on subjective judgments. More clearly, one could consider themselves more strongly in control when the context allows freedom to choose and presents several alternatives of actions as opposed to when one's choice is limited by external instructions.

It therefore appears that both prospective cues operating at the stage of action selection, and higher level beliefs in possessing stronger control when one has freedom to choose an action can affect subjective judgments of control. As the former operates before the action execution and production of outcomes, these processes could be argued to contribute prospectively to the agency judgments (Chambon et al., 2013). Higher level thoughts, on the other hand, would imply more strongly the contribution of retrospective processes on subjective judgments of control. At this point, nonetheless, it is important to note that the present results cannot definitively distinguish whether the influence of freedom and choice level on judgments of control was driven through prospective or retrospective processes (or a combination of both).

A final remark on the notion of action selection processes and fluency of action selection is in order. As noted before, previous studies suggested that dysfluency of action selection reduces the subjective ratings of control (Chambon & Haggard, 2012; Chambon et al., 2013; Haggard & Chambon, 2012; Wenke et al., 2010). The assumption purported in these studies was that the conflict between the primed and target action representations would decrease the fluency of action selection. In fact, recent studies seeking to elucidate the neural correlates of this assumption found supportive evidence that activity in IPC was increased with the input from DLPC that signals conflict monitoring (Chambon et al., 2013), as in the case of when actions primes and target actions are incompatible. In addition, disruption of IPC by TMS diminished the difference in judgments of control between compatible and incompatible primes (Chambon, Moore, & Haggard, 2014), suggesting that this area is causally related to the construction of agency judgments.

Regarding these studies, it is important to note that the notion of effort or selection fluency was only determined by the compatibility of action representations prior to action execution. The subjective aspect of effort experienced during action selection under various circumstances, however, was not considered. The former notion of effort can be considered as being in effect at the stage of action selection while the subjective judgment of effort is constructed after the action execution and refers to how effortful one perceives selecting an action. For the sake of simplicity, we call these two forms of effort “prospective” and “subjective” effort, respectively. Could prospective and subjective effort similarly influence the SoA? Two experiments (Experiments 4 and 5) in the present thesis attempted to address these questions by obtaining subjective ratings of mental effort experienced during action selection. Although the results of these studies did not reveal a clear statistical relationship between perceived effort and the SoA, the critical finding was that free-choice conditions were perceived as the least effort taking compared to decreased choice-level and instructed conditions. In particular, Experiment 4 showed that the effort ratings were systematically decreased as the number of action alternatives was varied from one to four. Note that the same trend was also observed with binding, demonstrated by increased estimates of action-outcome interval as the choice-level was varied from one to four. Similarly, in Experiment 5, participants experienced the least effort in choosing an action in the neutral-free condition where their choice was not preceded by an action prime. In this experiment, effort ratings were also varied by performing either prime-compatible or prime-incompatible actions, with higher effort experienced in the latter condition. The trend in binding was again similar, if not the same, as that of perceived effort across selection mode conditions, with greatest binding observed in the neutral-free condition followed by prime-compatible, primed-free, and prime-incompatible conditions.

At this moment, there are two important points to note. First, we do not argue that freedom entails effortless processing of action selection. Rather, it could be the case that when actions and outcomes are not contingent (as in Experiments 3-4) or when outcomes are indistinctive across different actions (as in Experiment 5), free selection of an action might be perceived as less effortful than following action instructions. This is most probably due to the fact that in the free-choice conditions (Experiments 3-4), processing of outcomes in relation to their causal actions was not involved in the selection processes. For instance, when one cannot predict the outcome of one of several actions or when several actions all produce the same outcome, one's ultimate decision on which action to take would be less likely to rely on the identity of outcomes compared to when each of these actions is contingently related to a distinct outcome.

Second, although the finding of Experiment 5 - that perceived effort was higher in the prime-incompatible condition compared to the prime-compatible condition - seems to parallel previous views of (prospective) effort in action selection (Chambon & Haggard, 2012; Chambon et al., 2013; Haggard & Chambon, 2012; Wenke et al., 2010), the present studies do not provide adequate evidence that prospective and subjective effort measure the same construct. However, they at least show that the notion of effort in action selection cannot be limited to the compatibility of action representations; the relationship between actions and outcomes as well as the number of alternative actions could also determine how fluently selection processes operate. Therefore, further investigation is required to advance the understanding of how prospective and subjective effort as well as effort and fluency might be related, and what other factors determine these aspects of action selection.

To sum up, overall results of Experiments 1, 3-5 suggest that freedom and choice level aspects of action selection prospectively contribute to intentional binding, whereas the influence of these aspects on subjective judgments of control can be driven by either prospective processes active during action selection or retrospective thoughts regarding the link between one's freedom in action selection and their sense of control. Furthermore, Experiments 4-5 pave the way for studying the notion of effort in action selection and its relationship with the SoA in a more comprehensive framework.

7.3 The role of outcome valence on the SoA

The contribution of outcome valence on the SoA is another topic of study that has received little attention. Only few studies directly examined whether the valence of action-outcomes could alter intentional binding and subjective judgments of agency. One such study used negative, neutral, and positive vocalizations as action-outcomes and showed that intentional binding was reduced with negative compared to neutral and positive outcomes (Yoshie & Haggard, 2013).

In the present thesis outcome valence was examined within different contexts in Experiments 2-4. In all of these studies, action-outcomes consisted of consonant and dissonant piano chords that are respectively regarded as pleasant and unpleasant sounding chords (Dell'Acqua et al., 2006; Dellacherie et al., 2011; Plantinga & Trehub, 2013; Shapira Lots & Stone, 2008). However, this characterization and preference for consonance have been suggested to be acquired through learning and could be specific to western music structures (Plantinga & Trehub, 2013; Vassilakis, 2005). In Experiment 2 thus, we recruited both western and non-western groups of participants and examined the influence of outcome pleasantness on intentional binding and FoC ratings over the outcomes. Interestingly, the results regarding the degree of binding showed that the non-western group was indifferent to the valence of outcomes while the western group displayed greater binding between pleasant compared to unpleasant outcomes and actions. Notably, this result highlights the importance of cross-cultural research in cognitive psychology. With respect to the FoC ratings, however, both groups reported having stronger control over pleasant than unpleasant outcomes. The following two experiments (Experiments 3-4), recruiting only western participants, and confirmed these results in FoC ratings. However, the results with binding did not reveal any difference between pleasant and unpleasant outcomes, which is discussed further below.

Based on the current studies and previous views, the most plausible explanation for feeling greater control over pleasant outcomes is linked to the notion of self-serving bias, which refers to the tendency to attribute the cause of desirable or positive-compared to negative- outcomes to the self (Bradley, 1978; Campbell & Sedikides, 1999). Furthermore, the current studies suggest that this effect can be observed in FoC ratings regardless of whether the outcomes are predicted (Experiment 2) or unpredicted (Experiments 3-4). Thus, subjective judgment of control over outcomes is more likely to be informed retrospectively by the valence of these outcomes.

With respect to the influence of valence on intentional binding, the methodological differences across the three experiments might account for the mixed findings. One important difference in this regard was that outcomes were contingent to their corresponding actions in Experiment 2 while they were unpredictable in Experiments 3-4. In the study by Yoshie and Haggard (2013), negative, neutral, and positive outcomes were presented in separate blocks and thus the identity of outcomes was as well predictable. The second difference was concerned with the temporal predictability of action-outcomes. Accordingly, the action-outcome interval was fixed to 250 ms in Experiment 2 while in Experiments 3-4, it was varied among 100 ms, 300 ms, and 500 ms. Therefore, the lack of either the identity or temporal prediction of outcomes in Experiments 3-4 could have undermined the influence of valence on intentional binding. With respect to the prediction of outcome identity, several views have highlighted the importance of action-outcome contingency on intentional binding (Haggard, 2005; Moore & Haggard, 2008; Moore, Lagnado, et al., 2009). However, other accounts have provided evidence that the size of binding did not differ between when the outcome identity was predicted versus when it was unpredicted (Desantis, Hughes, & Waszak, 2012). It might therefore be the absence of temporal predictability of outcomes that precluded the effect of valence on intentional binding in Experiments 3-4. Yet, this remains as an open question to be further explored by manipulating temporal predictability and valence within the same setting.

To recap, the overall results of Experiments 2-4 suggest that subjective judgments of control have a strong propensity to be influenced by outcome valence, whereas binding seems to be dependent on other factors such as temporal and identity predictions. The finding that subjective agency judgments were greater for pleasant than unpleasant outcomes regardless from the predictability of timing and identity of outcomes indicates that this effect is constructed retrospectively. Questions remain open, however, with regard to whether the absence of these predictions could have undermined the effect of valence on binding.

7.4 Relationship between intentional binding and FoC ratings

As mentioned in Chapter 1, the two-level account of the SoA proposed that the implicit measures of the SoA (i.e., intentional binding and sensory attenuation) might index the low level SoA while the explicit self-reports quantify the high level of SoA (Synofzik et al., 2008). The critical question regarding this distinction is then whether the implicit and explicit measures of the SoA are related and correspondingly, whether they rely on similar or distinct mechanisms.

One line of view put forward that subjective judgments of agency and intentional binding might rely on distinct mechanisms (Dewey & Knoblich, 2014; Ebert & Wegner, 2010; Obhi & Hall, 2011; Strother, House, & Obhi, 2010; Wen, Yamashita, & Asama, 2015). Wen et al. (2015), for example, examined the influence of arousal and action-outcome delays on both subjective judgments of agency and intentional binding. They found that arousal had enhancing effect on intentional binding while it did not influence the subjective judgments. Additionally, longer action-outcome delays increased the binding effect while weakening subjective control. In another study (Dewey & Knoblich, 2014), intentional binding and sensory attenuation were measured in operant (participants' key presses produce a tone) and observational conditions (participants passively hear the tones). After each block of operant condition, participants rated on a scale to indicate their subjective judgement of control over the tones. According to the results, binding and sensory attenuation effects were observed in the operant condition as expected. However, examination of the relationship among these measures indicated that neither of these measures was correlated with another.

The present thesis probed this issue by measuring both intentional binding and explicit judgments of agency in Experiments 2-5. While these measures were obtained as within-participants in Experiment 2, the following experiments conducted a between-participants approach in order to avoid any potential influence between these measures. The relationship between intentional binding and subjective judgments of agency can be considered in terms of i) whether they are similarly influenced by applied experimental factors and ii) whether there is a statistically significant correlation between them. Based on the previous views, as noted above, it appears that differences in the effects of experimental factors on the two measures (Wen et al., 2015) or a non-significant correlation between them (Dewey & Knoblich, 2014) could indicate that these two measures of the SoA rely on different mechanisms.

Within this framework, the results of Experiment 2 showed that although binding and FoC ratings were not correlated, pleasant outcomes enhanced both binding and FoC control ratings in the same direction for the western group. For the non-western-group, on the other hand, binding was found to be indifferent to the outcome valence while the FoC ratings displayed a similar trend to that in the western-group. In Experiment 3, having freedom to choose one's actions increased both binding and FoC ratings whilst the valence of action-outcomes influenced only the FoC ratings. Similarly, Experiment 4 showed that binding and FoC ratings were increased as the choice level varied from one to four, but the outcome valence influenced only the FoC ratings. In addition, binding and FoC ratings in these two studies were not found to be correlated. Finally, in Experiment 5, one's being free in choosing their action without any external influence on their choice similarly boosted intentional binding and FoC ratings and these measures were significantly correlated.

Therefore, these four experiments present rather mixed results regarding the relationship between intentional binding and FoC ratings. At the very least, however, it appears that the relationship between the two measures relies on the context of variables and processes (e.g., prospective and postdictive) that could be affected by these variables (see Figure 7.1 and Figure 7.2). Considering the present context of experiments (i.e., Experiments 2-5) thus, it could be contended that when the variable of interest (e.g., manipulating choice and freedom) operates through prospective processes (e.g., Chambon et al., 2013), both intentional binding and FoC ratings could similarly be influenced. If the manipulation is subject to retrospective processes, such as varying the valence of action-outcomes, it is more likely to influence the FoC ratings than intentional binding, as the latter is suggested to be driven largely by the prospective and predictive processes (Haggard, 2005; Moore & Haggard, 2008; Moore, Lagnado, et al., 2009).

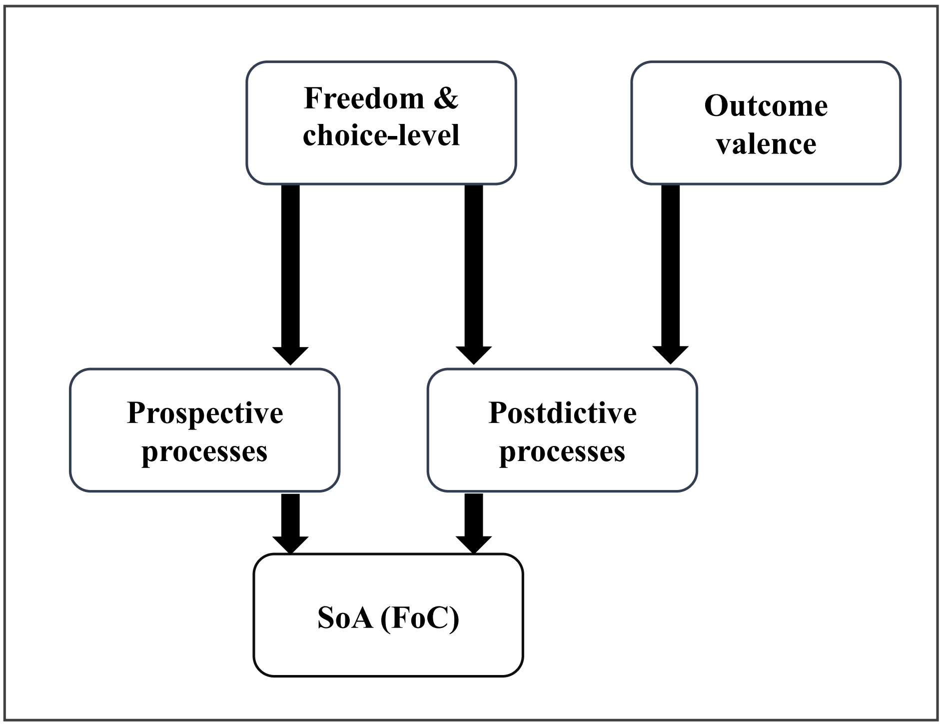


Figure 7.1 Schematic illustration of the processes through which freedom, choice-level, and outcome valence are suggested to influence the FoC judgments. The present findings demonstrate that the influence of freedom and choice-level could influence FoC judgments through either (or both) prospective and postdictive processes. The effect of outcome valence was found to be independent from the predictability of the action-outcomes, which suggests that FoC was influenced by outcome valence through the postdictive processes.

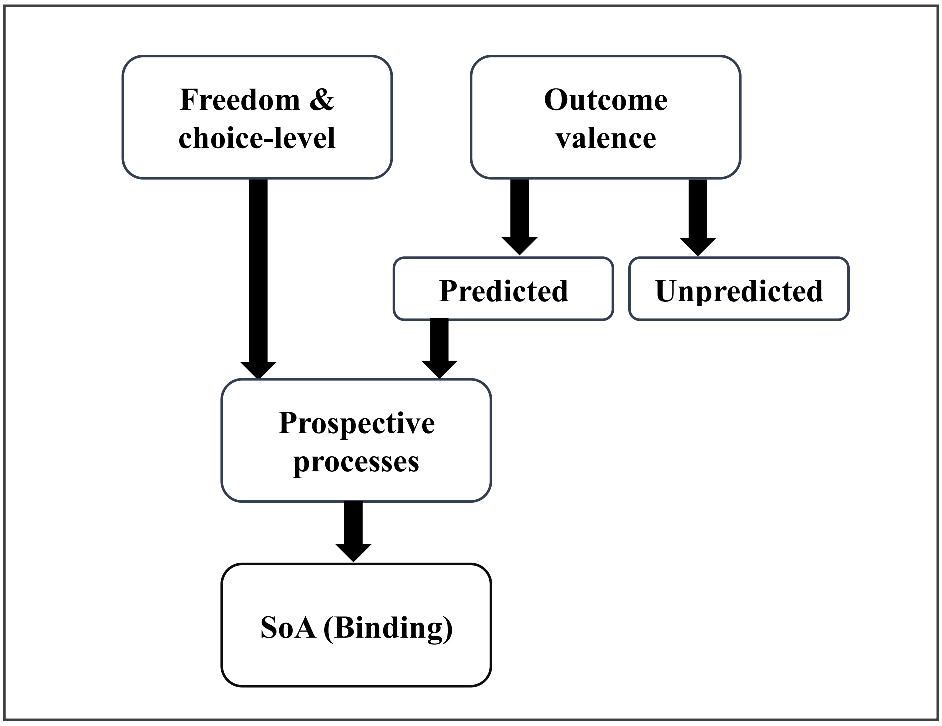


Figure 7.2 Schematic illustration of the processes through which freedom, choice-level, and outcome valence were shown to influence binding. The present findings demonstrate that the influence of freedom and choice-level could influence binding through the prospective processes. The influence of outcome valence, however, appears to depend on the predictability of action-outcomes. Experiments 2-4 showed that pleasant outcomes affected binding only when outcomes were predicted, indicating that binding relies heavily on the prospective processes.

7.5 Limitations and future directions

Although the present thesis proposed a strong relationship between the SoA and one's freedom and choice space in action selection, the current manipulations resemble a limited variety of scenarios that could be experienced in real life. In Experiment 1 and Experiment 5, for instance, all action alternatives produced a fixed outcome whereas most human actions are distinguished in the outcomes they produce. For example, one might choose to do work at a specific time instead of cooking dinner. These two actions would obviously yield different outcomes. From the perspective of the dynamic theory of intentions (Pacherie, 2008; see section 1.5), the D-intentions guiding these two actions would encode different contents (i.e., getting some work done vs. having the dinner ready). In this sense, the content of D-intentions in the current experimental contexts are more likely include the goal “to participate in the experiment and receive course credits” while the manipulations of freedom and choice-level target at P-intentions and M-intentions as they both involve in the selection of actions. A real-life scenario to which the context in Experiment 1 and Experiment 5 could be similar is, for instance, choosing to drive or to bike in order to go to the park- as they both yield the same outcome. Overall, although pressing keys in the current experimental contexts are not comparable to the more complex actions such as driving or biking, the present thesis showed that varying the choice-level in even such simple actions can alter the SoA.

Given these limitations, several future studies could be conducted to extend the scope and findings of the present experiments. The role of action selection processes could be further investigated, for example, by mapping each of several action alternatives with a distinct outcome. This would render the design more ecologically valid as most human actions are related to their outcomes and they involve the realization of a specific goal (Elsner & Hommel, 2001; Elsner et al., 2002; Haggard, 2008; Herwig et al., 2007). Within such a design, choice level or freedom as well as the value of outcomes could be manipulated to examine the potential interaction between these factors more clearly. This design could also reveal further aspects of the relationship between perceived effort in action selection and choice level. More clearly, one aspect of effort in selection as demonstrated in this thesis was that free and highest choice conditions were subjectively perceived as the least effort taking. On the other hand, if free selection among several alternatives involved a deeper processing of differential outcomes of actions, perceived effort in this case could be greater compared to performing an externally instructed action.

Another line of research could delineate further the neural correlates of fluency in action selection and its relationship with choice level. Previous research has shown that DLPFC and AG displayed increased activity when selection fluency was disrupted by incompatible action primes (Chambon et al., 2013). Importantly, AG has also been shown to signal discrepancies between predicted and actual outcomes of actions (Farrer et al., 2003, 2008). Moreover, RCZ was found to be engaged in selection of a number of task sets (Forstmann et al., 2006). The involvement of these areas could be examined further in a setting where choice level and predictability of action-outcomes are manipulated.

The body of experiments in this thesis could also be adapted to examine delusions of agency such as those observed in schizophrenia (Frith & Friston, 2013; Frith, 2005). The majority of people with schizophrenia experience the passivity phenomena triggered by the belief that some external agent is in control of their actions and thoughts. Recent work has begun to employ the paradigms used in SoA research to identify the characteristics of aberrant agency experienced by these patients. In this vein, it was found that perceived times of action and outcomes are hyper-bound in schizophrenia (Haggard et al., 2003; Voss et al., 2010). Additionally, sensory attenuation indexed by the N1 suppression was shown to be weakened compared to healthy controls (Ford, Mathalon, Kalba, et al., 2001; Ford, Mathalon, Heinks, et al., 2001). These abnormalities in the markers of agency were commonly attributed to impairments in predictive mechanisms and overreliance on retrospective processes (Blakemore et al., 2002; Frith et al., 2000; Frith, 2005; Synofzik & Voss, 2010). These assumptions on the impairments in schizophrenia could be advanced by further examining the role of action selection processes on intentional binding and judgments of control. Although predictive mechanisms are suggested to be flawed, it would be interesting to determine whether prospective cues such as the choice level and freedom in action selection could similarly influence intentional binding and FoC ratings in these individuals. Research concerned with disorders of agency could also prove useful to the advancement of diagnostic methods. For example, intentional binding measures could be applied to individuals (e.g., those with genetic predisposition or schizoid personality) who are susceptible to schizophrenia to identify the differences in binding compared to healthy individuals.

Finally, cultural differences in how individuals with different backgrounds experience the SoA would provide an additional avenue to examine whether the suggested mechanisms involved with the SoA could be shaped by sociocultural factors. This line of research could also illuminate the understanding of the relationship between cultural norms of morality and taking responsibility over one’s actions. For instance, cultures can vary in the characteristic of their self-construal, i.e. how individuals perceive themselves in relation to others (Hazel Rose Markus & Kitayama, 1991; Nisbett, Peng, Choi, & Norenzayan, 2001). Accordingly, it has been suggested that individuals with the independent view of the self tend to be more self-focused and autonomous in one’s needs or goals while those with interdependent self-construal regard these values in connection with the others in their culture (Markus &

Kitayama, 1991; Kitayama & Park, 2010). In this context, it would be interesting to examine agency across these cultures with different self views.

7.6 Conclusions

The present thesis investigated the influence of freedom and choice level in action selection and the valence of action-outcomes on the SoA. The foremost finding of the thesis studies is that both intentional binding and subjective judgments of agency are enhanced when one freely selects an action among a number of alternatives. Additionally, the degree of intentional binding and explicit agency were increased proportionally to the number of action alternatives available in the context. While these effects on intentional binding appear most likely to be driven by the prospective processes involved prior to action selection, it is possible that both prospective processes and high level inferences related to one's degree of freedom could have contributed to the results with the subjective judgments of agency. Examination of the influence of outcome valence demonstrated greater degree of control felt over pleasant compared to unpleasant outcomes. Importantly, this effect was found to be independent from the predictability of the outcomes. Regarding intentional binding, however, the current set of results suggests that the predictability of either the timing or the identity of outcomes might determine whether outcome valence can influence binding. More clearly, pleasant outcomes lead to greater binding than unpleasant outcomes provided that these outcomes were associated to specific actions and occurred at predicted times. When either of these dimensions is absent, binding was found to be insensitive to outcome valence. The present research has also provided some degree of evidence that the influence of valence on intentional binding could be amenable to cultural differences, which might potentially pave the way for future research to investigate cultural differences in agency. Finally, examination of the relationship between intentional binding and subjective judgments of agency showed that although freedom and choice level similarly influenced both measures, correlation analyses in the majority of studies did not reveal a significant relationship. Therefore, the overall results of the present studies support the notion that situational factors surrounding actions determine the contribution of predictive, prospective, and retrospective mechanisms to intentional binding and subjective judgments of agency (Moore & Fletcher, 2012; Synofzik et al., 2009, 2013). Among these factors, the present thesis highlights that one’s freedom in action selection and the availability of various action alternatives can strongly influence the SoA.

Appendix A

Demographic questionnaire used in Experiment 2

P#_____

1. Age:

2. Gender: ☐ Female ☐ Male

3. Handedness: ☐ Right ☐ Left

4. Country of birth: ______________________

5. How long have been living in Canada (years)?__________________

6. Please rate each group of countries indicating how much you like/prefer listening to their music and how much you are exposed to it compared to others:

Canada/USA/Europe
Preference : 1__2__3__4__5__6__7__8__9__10
Exposure : ______hours a week

Asia/Africa/Middle East
Preference : 1__2__3__4__5__6__7__8__9__10
Exposure : ______hours a week

7. Have you had any musical training?
Yes☐ No☐

8. If yes, please indicate the following:

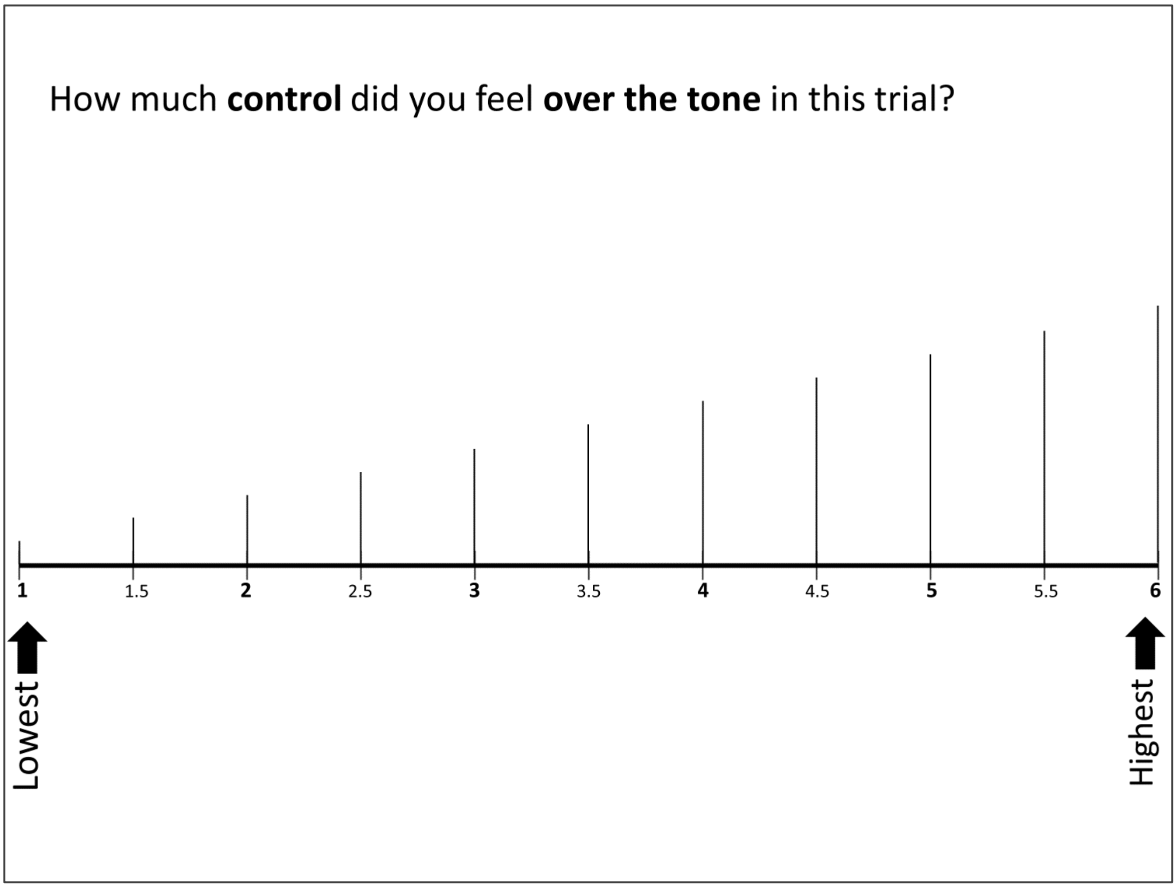
A) How long was the training?

B) Which instruments can you play (Please list the instruments and the average length of time you play per week)?

Instrument	**hours (a week)**
__________________	____________
__________________	____________
__________________	____________
__________________	____________
__________________	____________
__________________	____________
__________________	____________

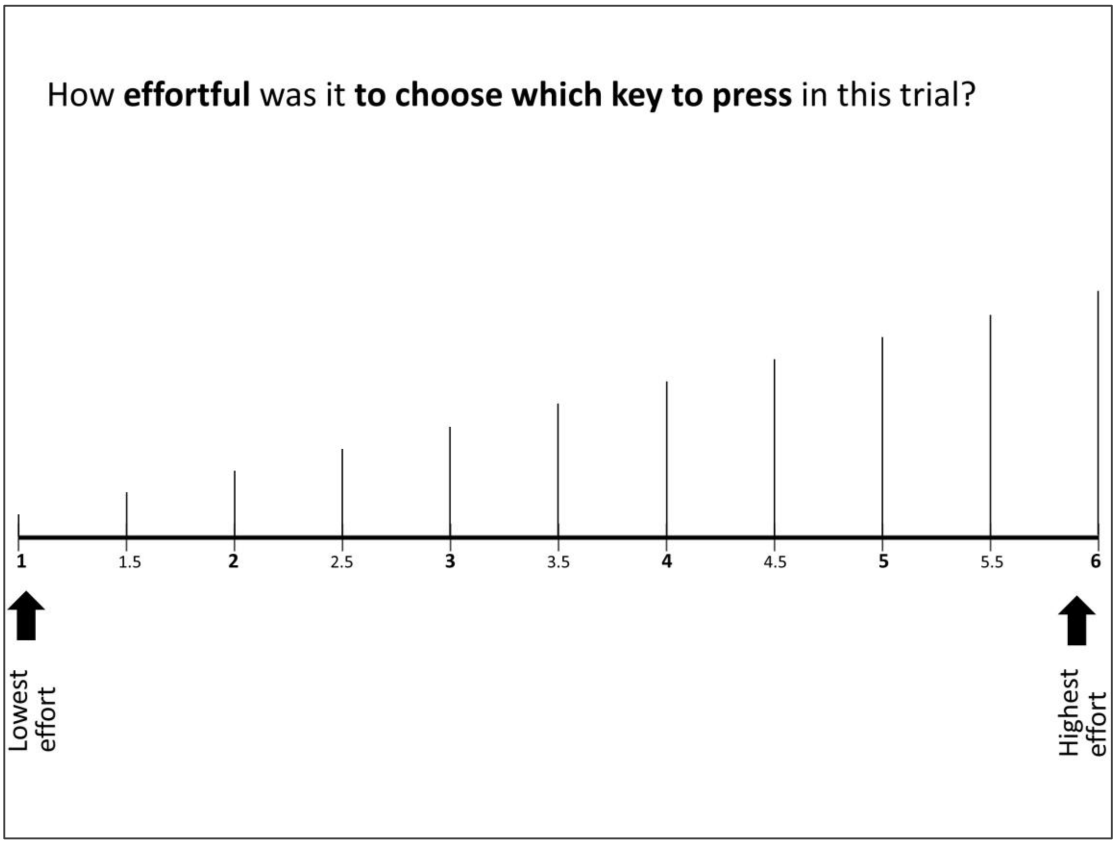
Appendix B

FoC rating scale used in Experiments 3-5

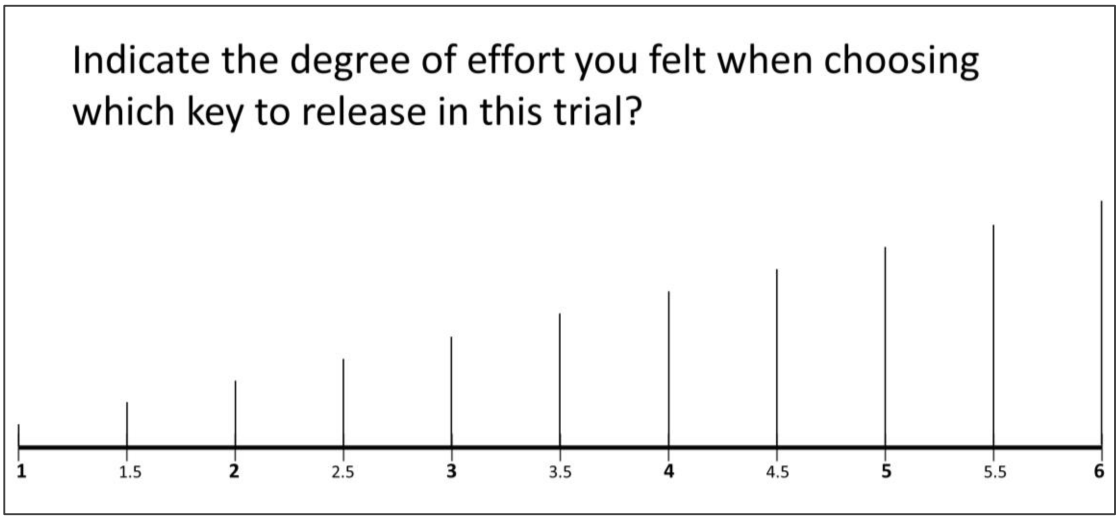


Appendix C

Effort rating scale used in Experiment 4

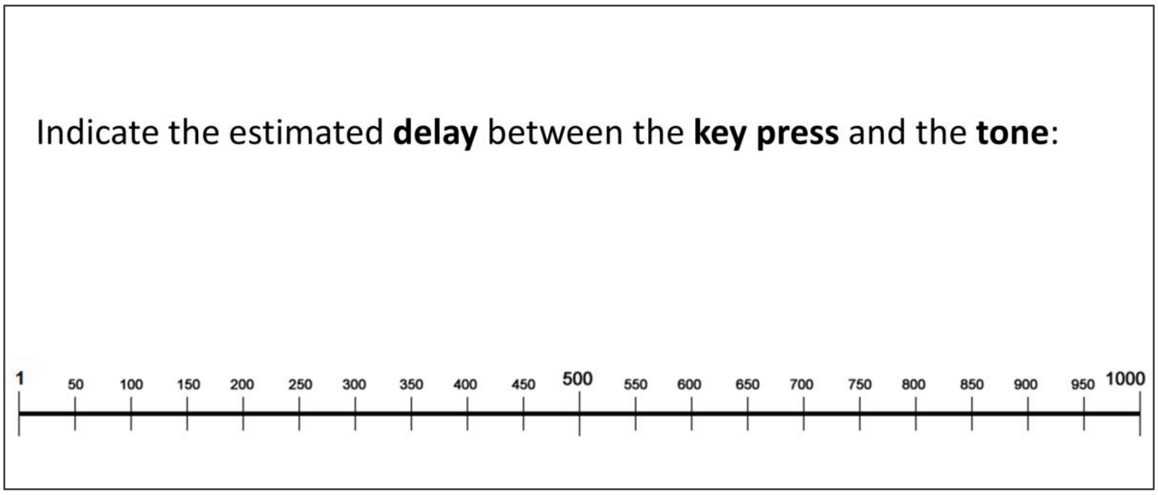


Effort rating scale used in Experiment 5

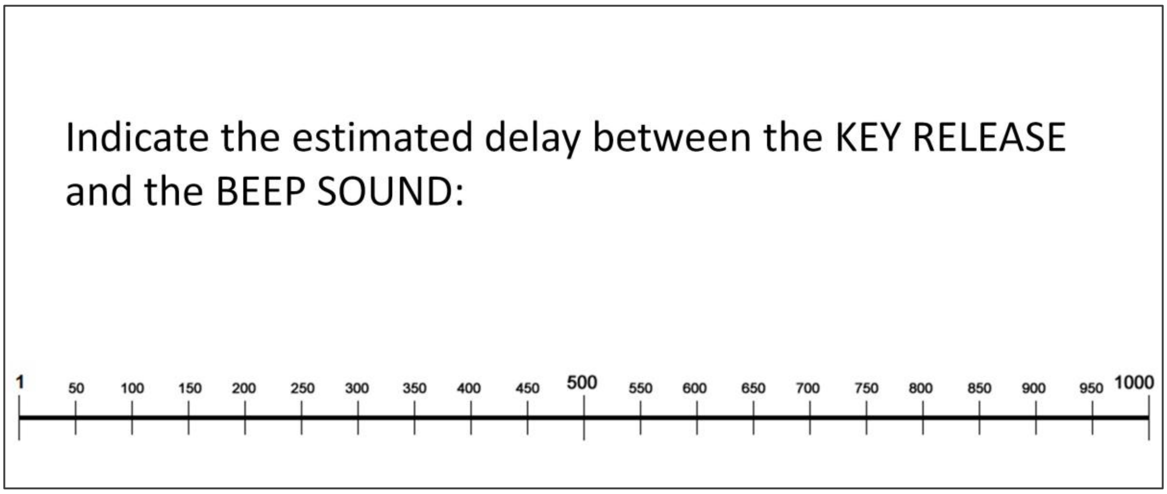


Appendix D

Interval estimation scale used in Experiments 3-4



Interval estimation scale used in Experiment 5



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