SOCIAL MODERATORS OF AGENCY

SOCIAL INFLUENCES ON THE SENSE OF AGENCY: THE EFFECTS OF ACUTE PSYCHOSOCIAL STRESS AND ACTION INSTRUCTION ON PERCEIVED AND IMPLICIT CONTROL

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Lay Abstract

This thesis explores the sense of agency—the experience of control over one's own actions. Across two chapters we investigated how stress and source of action instruction (whether instruction was directed by a person or an onscreen chatbot) affects feelings of control. The results of our first investigation (Chapter 2) found that individuals who experienced social stress felt more in control of their actions when there was a longer delay between their actions and their outcomes, suggesting that stress might sharpen our sense of agency in specific contexts. Our second investigation (Chapter 3) revealed that people feel the most in control when their actions are not instructed, less when instructed by another person, and even less when actions were instructed by an chatbot. These findings provide valuable insights into how everyday experiences, such as feeling stressed or following instructions from people or artificial agents, can shape our experiences of control.

Abstract

The experience of control is referred to as the sense of agency (SoA). Most healthy individuals experience agency for their actions however, this can be disrupted under specific contexts. Intriguingly, there is little research about how SoA is affected by stress, a common everyday experience, or action instruction by external agents. Across two empirical chapters and four studies, we employ both implicit (intentional binding; IB) and explicit (self-reported control ratings) measures to provide a multidimensional account of how agency is shaped in these social contexts.

In Chapter 2, we examined whether acute psychosocial stress modulates SoA. Stress was induced using the Trier Social Stress Test, followed by a task in which participants performed voluntary actions that produced auditory effects after varying time delays. In Study 1, explicit ratings of perceived control were obtained, while Study 2 employed IB as an implicit index of agency. Results from the implicit task revealed significantly greater SoA at longer delays (700 ms) under stress, suggesting a potential "stress-enabled agency boost" which may be linked to adaptive mechanisms, such as the fight-or-flight response.

In Chapter 3, we explored how externally instructed actions by another human versus an artificial agent (onscreen chatbot) affect SoA. In both studies, participants completed an action-effect timing task under three conditions: free choice, human instruction, and agent instruction. Findings consistently showed that SoA was strongest under free choice, diminished under human instruction, and was the lowest under agent instruction. Notably, both IB and control ratings followed a linear pattern, with human instruction falling between the extremes.

Together, these findings contribute to the growing literature on socially moderated agency, highlighting how stress and instructional contexts can influence individuals' subjective and perceptual experiences of control. This work also raises important implications for understanding agency in environments increasingly mediated by technology.

Acknowledgements

As I sat down to write this section, I was immediately struck by a profound sense of gratitude that I feel towards many individuals who have supported me throughout my graduate school journey. It is my sincere hope to acknowledge each of them with the appreciation and respect they deserve albeit, I know there will be names that I miss. Although my time at McMaster was relatively brief, I feel as though I formed many lasting connections and that my experience here was time very well spent.

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List of Abbreviations and Symbols

α	Alpha value
AI	Artificial intelligence
β	Beta coefficient
CI	Confidence interval
d	Cohen's *d*
dB	Decibel
F	*F*-statistic
Fig.	Figure
HPA	Hypothalamic-pituitary-adrenal
IB	Intentional binding
IE	Interval estimation
in.	Inches
M	Mean
ms	Milliseconds
N	Sample size
$\eta 2$	Partial eta-squared
p	*p*-value
rmANOVA	Repeated-measures analysis of variance
RP	Readiness potential
SD	Standard deviation
SE	Standard error
SNS	Sympathetic nervous system
SoA	Sense of agency
STAI	State-Trait Anxiety Inventory
t	*t*-statistic
TSST	Trier Social Stress Test

Declaration of Academic Achievement

This thesis has been prepared and structured in accordance with the sandwich thesis format approved by the McMaster University School of Graduate Studies. Four chapters comprise this thesis: Chapter 1 presents an introduction to the thesis; Chapters 2 and 3 consist of empirical studies; and Chapter 4 provides a general discussion of the research presented. Chapter 2 has been published in the journal *Consciousness and Cognition* and Chapter 3 is in preparation for submission.

I, Salina Edwards, declare that this thesis titled, **Social influences on the sense of agency: The effects of acute psychosocial stress and action instruction on perceived and implicit control**, and works presented in it are my own. I affirm my role as the primary author of each chapter presented in this thesis. All experiments were developed by myself in consultation with my supervisor, Dr. Sukhvinder S. Obhi. The empirical chapters presented below reflect the majority of my master's research conducted at McMaster University and therefore comprise the main body of this thesis. The specific contributions of myself and my co-authors on each chapter are detailed below.

Chapter 1: Introduction

Author contributions

- I declare that I am the sole author of this chapter.

Chapter 2: Preliminary evidence for a selective agency-boosting effect of psychosocial stress

Author contributions

- **Edwards, S.:** Conceptualization, Project administration, Methodology, Software, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing.
- **Galang, C. M.:** Data curation, Formal analysis
- **Fung, K.:** Investigation, Writing – original draft
- **Knight, A.:** Investigation, Writing – original draft
- **Obhi, S. S.:** Conceptualization, Supervision, Resources, Methodology, Writing – review & editing

Chapter 3: Effects of instruction source on the sense of agency: Humans vs. artificial agents

Author contributions

- **Edwards, S.:** Conceptualization, Project administration, Methodology, Software, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing.
- **Obhi, S. S.:** Conceptualization, Supervision, Resources, Methodology, Writing – review & editing

Chapter 4: General discussion

Author contributions

- I declare that I am the sole author of this chapter.

Chapter 1

Introduction

1.1 Advanced puppetry: Free will and illusion

The question of whether individuals are the author of their own actions, rather than passive subjects driven by a stream of unconscious mechanisms, has long occupied philosophical discussions tracing back to the early days of ancient Greek thought (Bobzien, 1998). Central to this enduring debate is the issue of free will, which is often divided into two opposing schools of thought: on one side is Libertarianism, which posits that human beings possess genuine freedom to choose their actions based on conscious intentions (a perspective notably popularized by Descartes and deeply embedded in much of Western thought); and on the other side is Determinism, which contends that every event, including acts of human behaviour, is caused entirely by preceding events and governed by the laws of nature (Clark et al., 2013). This dichotomy continues to shape contemporary discussions today across disciplines including philosophy, psychology, and neuroscience, raising fundamental questions about moral responsibility, agency, and the nature of human autonomy.

For a long time, the debate on free will was thought to surpass the limitations of empirical science however, the role of consciousness in voluntary action has since gained empirical traction in recent decades. The once solely philosophical concept of free will has very recently become a major topic of scientific inquiry (Schlosser, 2014). Landmark studies have shown that brain signals predictive of movement can occur before the individual becomes consciously aware of their intention to act. This original discovery was made by Kornhuber and Deecke in 1965, who identified an electrical potential in the brain that preceded voluntary finger flexion. This *Bereitschaftspotential*, or readiness potential (RP), sparked a wave of experiments that challenged the concept of free will (see Libet, 1985; Libet et al., 1993; Haggard & Eimer, 1999). Perhaps most notably, in the 1993 study by Libet and colleagues, it was claimed that these cerebral cortical activities (i.e., RPs) can occur approximately 300-800 milliseconds (ms) prior to an individual's intention to act. This report, along with Libet's many other seminal studies on this topic, has been widely acknowledged for its groundbreaking contribution to scientific discovery and for seemingly transcending the disciplinary boundaries that were once thought to exist between science and philosophy (see Libet, 2002). As a result of these findings, many neuroscientists generally assume the role of hard determinism, which emphasizes that conscious experiences are preceded by unconscious neural activity and because of this, free will cannot exist.

While some may argue that these findings only corroborate the evidence that free will is simply an illusion of the human mind, others often dismiss these reports, contesting that the claims made by Libet and colleagues are a result of poor scientific rigour with questionable methodology and far-fetched implications (Glynn, 1990; for a discussion see Schlosser, 2014). Yet, more recent work by Soon and colleagues (2008) attempting to reconcile for the shortcomings of Libet's early work found that brain activity predictive of decisions can be present as early as 10 seconds prior to one's reported conscious intent. Regardless of the scientific evidence and its merit, thinkers like Immanuel Kant (1899) continue to challenge this perspective from the standpoint of moral and societal functioning, and ask: *If free will does not exist, on what basis can individuals be held morally responsible for their actions*?

While this thesis does not aim to resolve the metaphysical debate about the existence of free will itself, it instead focuses on the subjective experience of *feeling* as though we are in control of our actions. Most people have the experience that they are the authors of their own actions—that the left foot follows the right simply because they have chosen to do so. This experience is referred to as the sense of agency (SoA; Gallagher, 2000; Haggard et al., 2002), and it represents a critical component of how we understand selfhood, responsibility, and intentional action. Perhaps the relevant question is not "Are your actions free?" but rather, "Do you *feel* as if your actions are free?"

1.2 The elusive nature of agency

Indeed, the study of agency is not a simple one. Scientific investigations into this topic began as recently as the early 21st century, and have since increased substantially over recent years. However, researchers have continuously faced a myriad of methodological issues due to the very attenuated nature of agency. Those interested in this subject were immediately faced with the very complex task of quantifying something that cannot be externally observed, due to it being merely a sense and not a strong one at that. The SoA is an experience regarded as being *phenomenologically thin*, meaning it often exists below the threshold of a strong, salient sensation and generally eludes conscious awareness (Clark et al., 2013).

To make more sense of this rather arcane idea, an example that a good mentor of mine used to employ was that of wearing eyeglasses. If you wear glasses of some sort, it is likely that you put them on to go about your daily life, or perhaps only on occasion for reading purposes. In any case, it is likely that, after some time goes by, you forget about the very fact that you are wearing glasses—you certainly are aware that they exist and that they are aiding your vision however, you are not consistently thinking about the fact that there are indeed glasses resting on the bridge of your nose at all moments of the day. That is, until you accidently smudge your lens and suddenly, the fact that you are wearing glasses becomes exceptionally unambiguous. The SoA works in a similar fashion—we experience this feeling for everyday, often mundane things, such as turning a knob to open a door. However, our capacity to experience agency is often limited, usually until something makes it very apparent, such as when the SoA becomes restrained—you turn the knob to open a door, and the door does not open (perhaps it is locked?). This experience differs markedly from other forms of conscious experiences, such as the sensation of touch, where our ability to feel the world around us is often largely phenomenologically vivid and relatively consistent, as opposed to thin and often transient.

Indeed, it is not just the fact that this experience is elusive that complicates its measurement—it is also the case that the accuracy of this experience is not always guaranteed (Moore, 2016). As the SoA is a conscious experience, there can sometimes be discrepancies in this experience and the objective reality. Some might experience this as a cognitive bias where they believe that they possess a greater ability to control or influence events than they actually do. A famous example of such *illusions of control* (Langer, 1975) was first recorded by sociologist James Henslin in 1967. While conducting research on St. Louis cab drivers, Henslin (1967) observed an intriguing pattern in how cab drivers behaved during a popular gambling game involving dice rolling. When rolling for a higher number, drivers would tend to toss the dice with greater force, and when rolling for a lower number, they often used a lighter toss to throw the dice. The fact that they might have been able to control the outcome of the dice rolls by applying varying levels of force is objectively impossible, yet this cognitive bias persists across areas such as gambling even today (see Clark & Wohl, 2021). Indeed, such illusions of control can exist across a variety of domains even beyond gambling and dice rolling. You yourself may have experienced this cognitive error the last time you crossed the street. While some might believe that the act of pressing a crosswalk button will cause the light to change at a quicker pace, in truth, many operate on timers and do not respond to input, no matter the frequency in which the button is pressed. Another example is that of elevator buttons: despite the frequency with which the close door button is pressed, the acting individual often has no control over the actual speed that which the door closes. These relatively well known examples, referred to as *placebo buttons* (McRaney, 2013), illustrate just how one might experience a greater SoA or influence over an action where none objectively exists, emphasizing the very nuanced and elusive nature of agency.

1.3 Measuring the sense of agency

One such consequence of this ambiguous experience is that the SoA becomes exceedingly difficult to measure. Generally, measures pertaining to the SoA can be divided into explicit and implicit categories. The earliest implicit measure was introduced by Haggard and colleagues in 2002. In this seminal article, researchers adapted the Libet clock method to study perceptions of time for actions and their subsequent effects. The Libet clock method was first introduced by Libet et al. in 1985 and was based on Wilhelm Wundt's complication pendulum apparatus; a foundational tool used for early studies on the time course of attention that was originally designed to measure the speed of thought (Wundt, 1883; for a fascinating history, see Rieber & Robinson, 2012).

Building on this, Haggard and colleagues (2002) used the Libet clock method to provide the first implicit measure of SoA. In this study, participants were asked to watch a rotating clock face and to judge the timing of events based on the clock's position (see Fig. 1). Across four conditions, researchers observed consistent perceptual shifts in how participants experienced voluntary actions (i.e., pressing a key on a keyboard) and the consecutive effects (i.e., hearing a tone play as an outcome of the keypress). In operant conditions, pairing an intentional, voluntary action with a delayed tone caused significant perceptual shifts. Specifically, when a voluntary action preceded the tone, participants perceived the action as happening later and the tone as occurring earlier than its objective temporal interval, suggesting a binding effect between the two events.

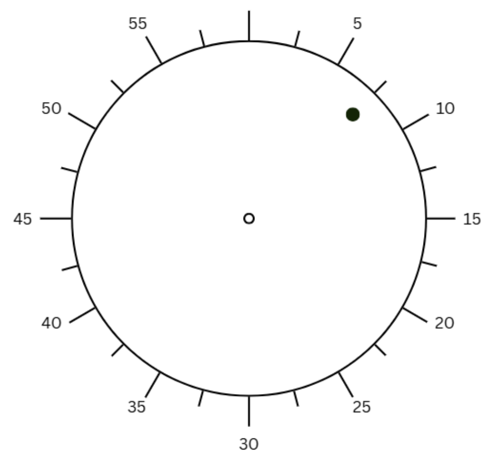

Fig. 1. ***The Libet clock.*** *In experiments using the Libet clock paradigm, participants observe a rotating clock and are commonly asked to indicate the clock's position at the moment an action occurred (e.g., the pressing of a key) and the moment an effect followed (e.g., the playing of a tone).*

Critically, involuntary actions induced using transcranial magnetic stimulation over the primary motor cortex reversed this binding effect, causing the temporal relationship between actions and their effects to appear further apart than its objective interval (Haggard, 2002). Authors concluded that the central nervous system may serve a distinct role in linking sensorimotor events related to voluntary actions. This integrative process, they argued, could be fundamental to how we experience ourselves as the agents of our actions.

Since the publication of this seminal report, this phenomenon, initially referred to as intentional binding (IB), has remained relatively consistent as a foundational metric in agency literature and has shaped a significant amount of research in the field (for an in-depth review, see Moore & Obhi, 2012). However, it should be noted that this method and its actual association with the SoA has since been the subject of considerable critique, with ongoing debate about whether IB truly reflects the SoA. Early arguments suggest that IB is merely an illusion of causality and one's experience of agency is largely dependent on the discrepancy when comparing the predicted and actual sensory feedback resulting from one's actions. As such, rather than reflecting IB per se, the observed temporal compression may stem from general cognitive processes that group together actions and events that are perceived as being contextually related, such as those occurring closer together, regardless of whether they are perceptual (e.g., visual or auditory stimuli) or motor (e.g., physical actions) in nature (Sato & Yasuda, 2005; Desantis et al., 2011; Gutzeit et al., 2023; Hoerl et al, 2020). Additionally, recent work has shown that intention, which was once considered a crucial component of this phenomenon, is not at all necessary for individuals to experience this temporal compression, positing that IB would be more accurately described simply as *temporal* binding (Buehner, 2012; Suzuki et al., 2019; Kirsch et al., 2019). Indeed, the extent to which temporal binding itself reflects an accurate and unobstructed measure of agency continues to be an ongoing topic of discussion however, this paradigm continues to be widely used by agency researchers today (e.g., Galang et al., 2025; Liu et al., 2024; Mariano et al., 2024).

Other implicit methods follow a structure similar to the original Libet paradigm but replace the rotating clock with an interval estimation (IE) approach. In this method, participants are typically asked to estimate, usually in ms, the temporal gap between an action and its resulting outcome without the use of a visual rotating clock. This estimation is usually provided either verbally, by directly entering a numerical value using a keyboard, or by selecting a value on a Likert-style sliding scale (e.g., Nakashima & Kumada, 2020). Although it differs slightly from the traditional Libet clock paradigms, this approach is generally thought to reveal similar insights into the temporal binding of actions and outcomes. However, in a recent systemic review and meta-analysis by Tanaka and colleagues (2019), it was revealed that the clock procedure can potentially demonstrate stronger effect sizes and greater sensitivity to perceptual moderators of binding in comparison to the IE method. Additionally, the use of IE methods has revealed temporal binding at intervals much longer than those identified with the Libet clock paradigm. For example, binding in an IE experiment has been found to occur at intervals as long as 4 seconds (Humphreys & Buehner, 2009), whereas in the original temporal binding experiment, binding remained robust at intervals of 250 ms and began attenuating at intervals of 450 or 600 ms (Haggard et al., 2002). This might suggest that the mechanisms underlying temporal binding are more context-dependent than previously assumed however, additional research that directly compares these two methods is necessary for further elucidating this claim.

Explicit measures of agency take a more straightforward approach—generally, these methods require participants to self-report their perceived agentic experience during a task. A common task involves having participants press a key which would be followed by a tone after a variable delay (e.g., 100, 400, or 700 ms). Participants would then be asked a question about their agentic experience or level of involvement in a task using Likert-style scales. For instance, they may be asked to rate their agreement with statements such as, “I caused the tone to play” (Dewey & Knoblich, 2014), or respond to questions like, “How much do you feel like you caused the tone to play?” (Edwards et al., 2025). Generally, participants report a stronger SoA over actions and their outcomes that have a shorter temporal contiguity compared to those that occur longer apart—a finding that aligns with the broader literature on temporal binding. However, these explicit methods are often biased and can be influenced by several variables. Because they rely on introspection, participants' responses can be shaped by expectations, task demands, biases, or even post-hoc rationalizations about causality (Miller & Ross, 1975, Tsakiris et al., 2005). For instance, participants may infer agency simply because the tone reliably follows their action, regardless of whether they experienced a genuine sense of control. Additionally, social desirability and the phrasing of agency-related questions may further distort responses, as there is no universally applicable way to phrase questions about the SoA that fits all experimental contexts.

Adding to the complexity, it remains uncertain whether implicit and explicit measures of agency truly capture the same underlying construct. Generally, implicit SoA is considered to fit within the pre-reflective model of agency, whereas explicit SoA is considered to fit in the reflective model. In pre-reflective models, SoA is an automatic process that accompanies most voluntary acts. That is, the implicit feeling of agency does not require a reflective act of consciousness to determine one's level of involvement in conducting an action (Synofzik et al., 2008; Moore et al., 2012). This aspect of agency is thought to be informed by sensorimotor processes involving efferent motor information and sensory feedback mechanisms. Within the reflective model, conscious post hoc evaluations about one's involvement in an action is required and as such, explicit attributions of agency are made. It is suggested that this model of agency relies on high-level sources of information, such as social and contextual cues, to ascribe its involvement (Moore et al., 2012).

Some researchers have conducted identical experiments employing implicit vs. explicit measures and have found little to no correlation between the two (e.g., Moore et al., 2012; Dewey & Knoblich, 2014; Lafleur et al., 2020). On the contrary, other studies have demonstrated a connection between the two, yielding comparable results that suggest similar inferences of agency across both methods (e.g., Imaizumi & Tanno, 2019; Edwards et al., 2025). Indeed, this discussion is still a matter of debate, further highlighting the multi-faceted nature of agency.

1.4 Neural correlates

In addition to implicit and explicit measures, many researchers have aimed to identify the neural correlates of agency in order to establish a physiological foundation for agency-related processes. Early work in this area has faced challenges in identifying neural pathways associated with the presence of a strong SoA but have revealed activation in the left and right angular gyrus in the absence of agency experienced during actions and events with temporal incongruence (Farrer et al., 2003; 2008). Currently, a broad network of neural structures is believed to underlie the processes associated with a diminished SoA. In a recent whole-brain meta-analysis, Zito and colleagues (2020) identified consistent patterns of neural activation across multiple neuroimaging studies investigating the SoA. The results revealed three significant clusters of activation for reduced agency within the bilateral temporo-parietal junction: the right superior temporal gyrus, the left inferior parietal lobe, and the left middle temporal gyrus. Intriguingly, however, no significant clusters were observed for experiences of increased agency (Zito et al., 2020).

Several brain regions have been implicated in the experience of agency, many of which overlap with networks involved in motor intention. These include the rostral and posterior areas of the medial frontal cortex, the anterior and posterior insula, the parietal lobules, the occipital lobe, and the cerebellum (for a meta-analysis, see Seghezzi et al., 2019). Notably, the occipital lobe has been highlighted as a potentially significant contributor to agency-related experiences—this region is suggested to play a role in the integration of matching motor output with its corresponding visual consequences. Some research using electroencephalography has uncovered distinctions in the processing of action outcomes in conditions of high versus low SoA. In a study by Caspar and colleagues (2016), individuals who were coerced into conducting an action displayed a reduction of the auditory N1 amplitude in comparison to individuals in a free choice condition where no coercion was present. This finding was robust for coerced actions that were followed by both harmful and non-harmful outcomes where the SoA was consistently decreased.

Intriguingly, the activation of areas associated with agency-related processes using neurostimulation techniques has been shown to have potential therapeutic benefits in clinical populations. For instance, a recent study by Lin and colleagues (2024) used intermittent theta-burst stimulation to target the left dorsolateral prefrontal cortex in individuals experiencing depressive symptoms. The findings revealed that induced activation of this area was significantly associated with enhanced self-attributed agency, particularly following goal achievement under conditions requiring low cognitive effort. Furthermore, the study identified a broader network of frontal brain regions, including the right premotor and supplementary motor areas and the left inferior frontal gyrus, whose activation correlated with agency-related judgments. Overall, these findings underscore the potential for neuromodulation approaches to play a role in mediating the effects of helplessness that is commonly associated with depression through increases in agency, offering new targets for therapeutic interventions.

Attempts to provide empirical evidence for the SoA using physiological measures (i.e., skin conductance, heart rate) have not yet been successful in the literature, suggesting that the SoA may have a weak connection to bodily sensations or physical feelings (David et al., 2011). Overall, the neural correlates involved in agency-related experiences involving a positive SoA are currently poorly understood and consistent patterns are lacking in the literature.

1.5 Social moderators of agency

Indeed, despite the inherent complexities of studying a phenomenon which was once considered too elusive to measure, the result of much research in recent years has provided a strong basis for the empirical investigation of agency and its underlying processes. As such, the present thesis contributes to the literature on SoA by examining how social factors, particularly acute stress and the source of action instruction (e.g., human vs. nonhuman instruction), moderate the individual experience of agency. Through a series of empirical studies, this thesis aims to clarify how these factors shape individuals' agentic experiences, thereby contributing to a more nuanced understanding of agency in everyday life.

The first empirical chapter within this thesis (Chapter 2) investigates the influence of acute psychosocial social stress on SoA. This report has recently been published in the high-impact journal *Consciousness and Cognition* (see Edwards et al., 2025) and is accessible through open access. In this report, we use both implicit and explicit methods of measuring SoA to provide a more nuanced understanding of how stress might affect these experiences of agency. The findings contribute to a growing body of literature suggesting that stress can alter cognitive and perceptual processes related to one's experience of control.

Building upon this work, Chapter 3 explores the effects of action instruction on SoA. Across two studies, we explored the question of how the source of action instruction—specifically whether an individual is instructed to conduct an action by another human or an artificial agent (i.e., onscreen chatbot)—influences the experience of agency. As with Chapter 2, both implicit and explicit measures were used to attempt to capture the complexity of agency-related processes under varying social conditions. This chapter is presented in a publishable format and is currently under preparation for submission to a scholarly journal.

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Chapter 2

Preliminary evidence for a selective agency-boosting effect of psychosocial stress

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Preface

In most healthy adults, the subjective SoA and objective control are closely aligned: when an individual executes a voluntary action, they are likely to feel a subjective sense of control over the action and its outcomes (Haggard, 2005; Moore, 2016). However, there are some circumstances in which subjective feelings of control can be misaligned in both clinical and non-clinical samples (Malik et al., 2022). For instance, disruptions in SoA are found to be a relatively common experience in individuals across schizophrenia spectrum disorders (Garbarini et al., 2016; Graham et al., 2014; Jeannerod, 2009; Krugwasser et al., 2022). Individuals within this population often report misattributions in whether action was caused by themselves or generated by an external force (Frith et al., 2000).

These *delusions of control*, often described in terms of a disrupted SoA, can manifest to the extent that an individual feels a loss of control over both their external and internal actions, including thoughts, emotions, somatic experiences, and awareness of motor action (Graham et al., 2014; Robinson et al., 2016). Moreso, this selfdisturbance is a striking aspect of psychosis, which is often found in individuals at risk for developing schizophrenia (Krugwasser et al., 2022; Maeda et al., 2013).

Intriguingly, stress has long been acknowledged as a factor in the development of psychopathological conditions that are characterized by a disturbed sense of control (Myin-Germeys & van Os, 2007; Zubin & Spring, 1977). Exposure to day-to-day stressful occurrences has been found to predict both concurrent and future psychological symptoms (Kanner et al., 1981). Furthermore, there is compelling evidence that psychosocial stress is particularly implicated in the development of psychotic symptoms (Johns et al., 2004; Os et al., 2009).

Stress is a fundamental aspect of the human experience and, like agency, is ubiquitous to daily life. Despite the well-known fact that stress can lead to a variety of health complications that impact both psychological and physical functioning (O'Connor et al., 2021), there has been a paucity of research on the experience of agency under stress. As such, the first manuscript presented in this thesis aims to address this gap by examining the effects of stress on the SoA, offering new insights into how stressful experiences may shape individuals' perceptions of control over their actions and their consequences.

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Preliminary evidence for a selective agency-boosting effect of psychosocial stress

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Abstract

Sense of Agency (SoA) arises from the perception of being in control of one's own actions and their outcomes. Many contextual and individual difference variables have been found to influence the SoA. Here, we focused on elucidating the potential relationship between psychosocial stress and the SoA across two studies. Psychosocial stress was induced via the Trier Social Stress Test (TSST) and agency was assessed in a task involving production of a voluntary action that resulted in an auditory effect 100 ms, 400 ms or 700 ms later. In Study 1, we used an explicit self-reported measure of agency in the form of a perception of control rating, and in Study 2 we used an implicit measure of agency in the form of temporal estimates of the interval between an action and an effect, so called intentional binding (IB). The results of Study 1 (explicit) showed that undergoing the TSST relative to a control condition increased SoA for outcomes that occur after a 700 ms delay. However, this effect was weak and did not survive correction for multiple comparisons. In Study 2 (IB), temporal estimates in the stress condition were significantly shorter than those in the control condition, exclusively for action-effect time delays of 700 ms. We conclude that this increased IB for 700 ms delays after induction of psychosocial stress reflects a potential "stress-enabled agency boost", and that such an agency boost might be associated with the fight-or-flight stress response. Directions for future research are suggested.

Keywords: *Sense of agency (SoA), stress, intentional binding (IB)*

2.1 Introduction

The experience of control over actions and their outcomes can be observed in everyday actions, such as flicking a switch to turn on a light, and is referred to as the Sense of Agency (SoA; Haggard & Tsakiris, 2009). Often, the causal attribution that one's action resulted in a particular outcome is an almost subconscious experience—rarely, if ever, do we pause to mindfully appraise our role in the causal chain of 'action' to 'outcome' (Haggard, 2017). These rather faint experiences can be described as *phenomenologically thin*, often eluding direct observation (Haggard, 2005). Nevertheless, SoA is essential for humans to maintain responsibility for voluntarily performing actions that impact the external world.

An intriguing but underexplored topic is the relationship between stress and SoA. Like agency, stress is a fundamental aspect of the human experience and is ubiquitous in daily life. Notably, stress has long been acknowledged as a factor in the development of psychopathological conditions that are characterized by a disturbed sense of control, highlighting its potential association with SoA (Myin-Germeys and van Os, 2007; Zubin and Spring, 1977). Stern and colleagues (2020) were among the first to explore this potential relationship between SoA and stress. Fourteen participants were recruited from a clinical population to engage in a virtual reality task. In this within-subjects study, participants engaged in a 'neutral' (control) block followed by a 'stress' block. Participants placed their hand beside a barrier while a realistic virtual hand appeared on a screen in front of them. They were then instructed to fold their index finger while the virtual hand mimicked their movement after a randomized delay. An explicit method was used to measure what the authors termed *embodied* SoA – the SoA that reflects the link between intention and action – wherein, after each trial, participants made explicit ratings of their subjective feeling of control over each movement on a Likert scale. The results of this study did not indicate any significant effects of stress on SoA.

Many other studies on SoA use an approach that infers agentic experience via an assessment of the relationship between the perceived time of an action and its consequent sensory effect. In this approach, researchers use the perceived temporal interval between an action and an effect to determine the degree of "intentional binding (IB)" which refers to the finding that a voluntary action and its consequent effect (often a tone in experiments) are attracted toward one another in perceived time relative to when an action is not made voluntarily (Haggard et al., 2002). In one recent study using this paradigm, Chu and colleagues (2023) found a relationship between SoA and stress. In this between-subjects study, thirty-four participants from a university sample engaged in an IB task in either a 'stress' or 'control' condition. The results of this study revealed significant differences in temporal perception of actions and effects. Chu et al. (2023) concluded that stress weakens the SoA, in contradiction with Stern et al. (2020) that found no effect of stress on embodied SoA. These contrasting findings underscore the complexity of the relationship between stress and SoA and highlight a potential differential impact of stress on distinct facets of agency. Stress is a pervasive factor in daily life and plays a pivotal role in the onset and progression of psychopathological conditions characterized by impaired control. Further investigating how stress influences SoA could, in the future, provide valuable insights into the mechanisms underlying these conditions.

This study seeks to contribute to the existing literature on the effects of stress and the SoA. Across two experiments, we investigated the relationship between acute psychosocial stress and SoA, employing explicit self-report measures of control (Study 1) and implicit IB measures (Study 2) of SoA. We hypothesized that individuals undergoing a stressful situation would exhibit negative impairments in SoA, overall reporting reduced feelings of control over their actions in Study 1 and showing reduced binding in Study 2.

2.2 Study 1: Explicit SoA

2.2.1 Methods

2.2.1.1 Participants

Forty-two participants between the ages of 18 and 26 (28 female, 13 male, one non-binary; M_{age} = 18.4, SD_{age} = 2.1) were recruited from McMaster University. For this study, data were collected for one school semester (four months) until time limitations were met and the participant recruitment pool was diminished. All participants were required to have normal or corrected-to-normal vision and hearing to enroll in the study. Exclusion criteria included a current or previous diagnosis of major depressive disorder, bipolar disorder, generalized anxiety disorder, posttraumatic stress disorder, or head injury. Participants were remunerated 0.5 course credits for every 30 mins of their time.

2.2.1.2 Materials: STAI, TSST, and TSST-placebo

The STAI was used to measure participant anxiety levels to determine the effectiveness of stress. This questionnaire is consistently supported in the literature as a reliable measure of current (state) and general (trait) differences in participants' anxious moods (Grös et al., 2007; Spielberger et al., 1971) and has previously demonstrated sensitivity to the detection of stress, whereby exposure to situations that activate stress responses are associated with increased anxiety and activation of the SNS (Kabacoff et al., 1997; Willmann et al., 2012). Given the strength of its reliability, we employed the STAI as the measure of stress in this report (Narvaez Linares et al., 2020).

The Trier Social Stress Test (TSST), originally developed by Kirschbaum and colleagues (1993), is considered the gold-standard paradigm for reliably inducing acute psychosocial stress in a controlled laboratory setting (Allen et al., 2017). The TSST involves a presentation-style interview followed by a difficult arithmetic test performed in the presence of evaluative judges. The combination of these elements (i.e., anticipation, public speaking, social evaluation, and cognitive arithmetic) is effective in reliably stimulating the hypothalamus–pituitary–adrenal (HPA) axis and sympathetic nervous system (SNS), allowing it to produce stress in most individuals (Allen et al., 2014; Het et al., 2009; Kirschbaum et al., 1993).

In a recent systematic review, guidelines for the standardization of the TSST were proposed to address concerns regarding validity and reproducibility due to its numerous methodological variations (Narvaez Linares et al., 2020). In adhering to the suggested guidelines, two opposite-gendered individuals (one male, one female) were chosen to act as judges in the TSST. Each judge was instructed to maintain neutrality and refrain from providing any verbal or visual feedback to participants. Participants were also led to believe that their presentation was being recorded using a camera set on a tripod for later evaluation of their non-verbal performance (Narvaez Linares et al., 2020). This, however, was deceptive as no video recording of the experiment was captured. Following the suggested standardization of the speech process, participants were allotted five minutes to prepare for their interview using a pen and paper. In the absence of their notes, they then began a five-minute speech where they must convince the judges why they consider themselves the ideal candidate for their 'dream job' (Narvaez Linares et al., 2020). Participants then engaged in a five-minute verbal arithmetic challenge, as initially described in the seminal work of Kirschbaum and colleagues (1993), where the participants had to verbally subtract 13 from 1022 in front of the judges (Narvaez Linares et al., 2020).

Participants in the control condition engaged in a placebo version of the TSST, designed to resemble the original TSST without activating the stress response of participants (Het et al., 2009). Similar to the Stress condition, participants were given five minutes to prepare to give a speech about a vacation, novel, or book they previously enjoyed. They were then led into the empty room to give their 5-minute speech in front of a camera that they believed was recording their performance. The participant was then instructed to begin a verbal arithmetic task for another five minutes where, starting at zero, they were to count upwards in increments of five.

2.2.1.3 Experimental design

This study used a 2 (Condition: Stress, Neutral) x 2 (Time: Pre, Post) x 3 (Delay: 100, 400, 700 ms) mixed design, with Condition as the between-subjects factor and Time and Delay being within-subjects. Questionnaires to obtain explicit SoA measures and the State-Trait Anxiety Inventory (STAI) were administered at each timepoint (Pre and Post) to obtain pre- (baseline) and post-test measures of participant SoA and stress (Spielberger et al., 1971).

The explicit agency task was developed using PsychoPy (v. 2023.2.2) and presented on a 15.6" Dell Inspiron laptop. Participants were required to wear headphones for the duration of this task with the volume set to 70 dB. At the presentation of a fixation cross, participants were instructed to press the spacebar on the keyboard in their own time (see Fig. 1). The keypress triggered a tone that was played after a randomized delay of either 100, 400, or 700 ms. After hearing the tone, participants were asked to indicate how much control they felt they had when causing the sound to play on a Likert scale of 1 ('No control at all') to 5 ('Complete control').

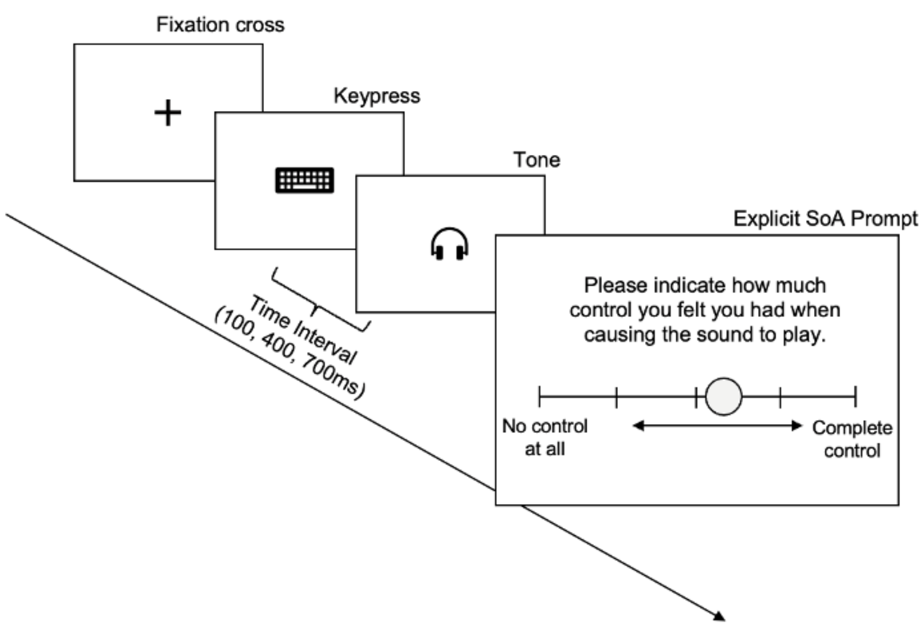

Fig. 1. ***The explicit SoA task.*** *At the onset of a fixation cross, participants pressed a key on the keyboard. Following a randomized delay of either 100, 400, or 700 ms a tone was played. Participants were then asked to indicate their perceived self-control in causing the sound to play on a Likert scale.*

2.2.1.4 Procedure

On an individual basis, participants were invited to a room in the lab where they received information about the study. After indicating consent, participants completed a short demographics questionnaire followed by the 40-item STAI, which was embedded within 20 filler questions to prevent participants from deducing the true purpose of the study. After practicing the SoA task for three trials, participants completed 30 pre-test experimental trials. Random selection was used to distribute participants into either the Stress (experimental; *N* = 21) or the Neutral (control; *N* = 21) group.

In the Stress condition, participants underwent a standardized version of the TSST (Narvaez Linares et al., 2020). Participants were led into a testing room and allotted five minutes to prepare for an interview where they had to convince two judges why they consider themselves the ideal candidate for their 'dream job.' Participants were informed th at the session would be recorded for further analysis however, this aspect of the experiment was deceiving as no video data of any participants was recorded. During the preparatory period, participants were provided with a pen and paper and left alone in the room to prepare for the interview. After this period, two judges (one male and one female) entered the room and collected the preparatory notes. Participants were instructed to stand 54 in. in front of a table while the judges pretended to turn on a camera that was attached to a tripod. A five-minute timer was set, and participants began their speech. During the interview, the judges remained neutral-faced and pretended to type notes on laptop computers, only interacting with participants if they stopped talking at any time by saying "Please continue." After five minutes, participants began the challenging cognitive arithmetic task where they were required to verbally subtract 13 from 1022 for another five-minute period. If a mistake was made at any time, participants were instructed to restart. After this task, participants completed the post-test SoA task for 30 trials, followed by the 40-item STAI embedded within 20 additional filler questions. See Fig. 2 for a depiction of the study procedure.

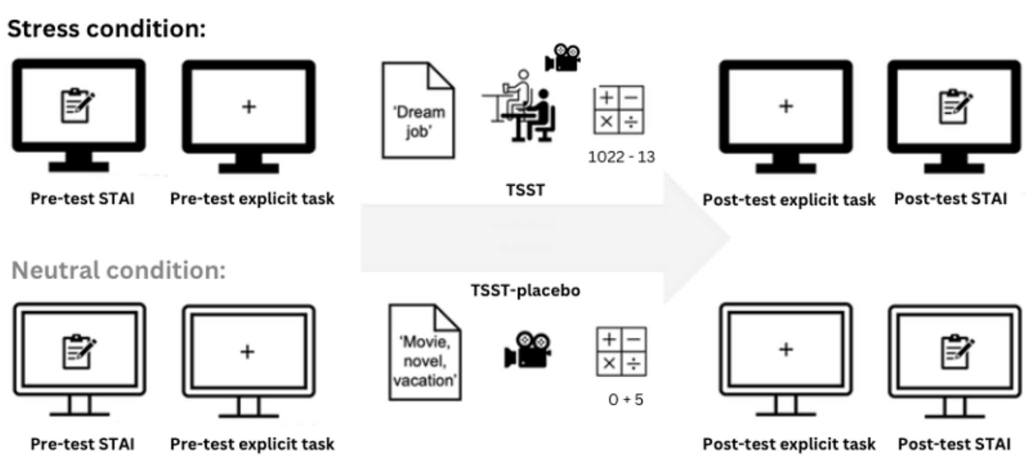

Fig. 2. ***Depiction of the experimental procedure for Study 1.*** *Row one depicts the experimental (Stress) condition where participants engaged in the pre-test STAI survey and explicit SoA task, followed by the TSST. Finally, participants completed a post-test explicit SoA task and STAI survey. Row two depicts the control*

(Neutral) condition where participants engaged in the same pre-test measures, followed by the TSST-placebo. Similarly, participants completed a post-test explicit SoA task and STAI survey.

In the Neutral condition, participants engaged in a placebo version of the TSST. After completing the baseline STAI and explicit SoA task (which included three practice trials followed by 30 experimental trials), participants were given a pen and paper and instructed to prepare for a talk about a recent movie, novel, or vacation they had enjoyed. After five minutes, and without their preparatory materials, they were instructed to stand 54 in. in front of a table with a camera facing them. Participants were told that their speech was being recorded; however, unknown to each participant, the camera was not turned on and no video data were collected. At the end of this period, participants were instructed to begin a verbal arithmetic task where, starting at zero, they were to count upwards in increments of five. Finally, after finishing the TSST-placebo, participants completed 30 post-test trials of the explicit SoA task, followed by the STAI questionnaire.

All participants were debriefed, thanked, and remunerated for their time. Participants in the Stress condition were given the option to watch a 3-minute mood-boosting video to mediate the physiological and psychological effects of the TSST. The entire duration of each study was approximately one hour.

2.2.2 Results

2.2.2.1 Data analysis plan

Data processing, visualization, and analyses were conducted using R v.4.4.2 (R Core Team, 2024) with R packages tidyverse (Wickham et al., 2019), lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), emmeans (Lenth, 2024), and ggplot2 (Wickham, 2016). To determine the effectiveness of the TSST in inducing stress, comparisons of participant STAI scores were analyzed using the lme4 package in R with the following model:

$$\text{Score} \sim \text{Condition} * \text{Time} + (1 \mid \text{ID})$$

Condition, Time, and the interaction between the two were included as fixed effects on participants' STAI scores. Random slopes and intercepts were included for participants (ID).

To explore the effects of stress on participants' self-reported agency, a linear mixed-effects model was fit with the following structure:

$$\text{Ratings} \sim \text{Condition} * \text{Time} * \text{Delay} + (\text{Time} + \text{Delay} \mid \text{ID})$$

The model included fixed effects for Condition (Stress vs. Neutral), Time (pre- vs. post-test), and Delay (100, 400, 700 ms), as well as their interaction on participants' self-reported agency scores (Ratings). Random intercepts and slopes were included for Time and Delay across participants (ID) to account for individual variability. Post-hoc pairwise comparisons for both models were conducted using the emmeans package in R.

2.2.2.2 Effectiveness of the stress manipulation (TSST)

A linear mixed-effects model (Satterthwaite's method) was conducted to examine the effects of Condition (Stress vs. Control) and Time (Pre vs. Post) on participants' STAI Scores. Cronbach's alpha values for the pre- and post-test STAI (40-item) were 0.91 and 0.95, respectively, both indicating excellent internal consistency. There were no statistically significant main effects for Condition ($\beta = -9.95$, $t = -1.85$, $p = 0.07$) or Time ($\beta = -1.38$, $t = -0.49$, $p = 0.63$). The interaction between Condition and Time was statistically significant ($\beta = 10.67$, $t = 2.67$, $p = 0.01$) showing that the difference in pre- to post-test STAI scores is dependent on the condition that participants were in.

To further explore these findings, post hoc comparisons (Kenward Roger, using the Bonferroni method for corrections) were conducted. The results showed a statistically significant difference in pre- and post-test STAI scores in the Stress condition ($t(40) = 3.29$, $p = 0.01$), showing that participants' pre-test scores were significantly lower ($M = 82.33$, $SE = 3.8$, 95% CI [74.71, 89.95]) than post-test scores ($M = 91.62$, $SE = 3.8$, 95% CI [84, 99.24]). This indicates that participants in the Stress condition were experiencing significantly elevated stress after engaging in the TSST. In the Neutral condition, there was no statistically significant change in participant STAI scores ($t(40) = -0.49$, $p = 0.96$) from pre- ($M = 92.29$, $SE = 3.8$, 95% CI [84.67, 99.91]) to post-test ($M = 90.9$, $SE = 3.8$, 95% CI [83.28, 98.52]). These findings suggest that the TSST-placebo was effective in providing a control manipulation that maintained similar elements to the TSST without affecting the stress level of participants. Data is visualized in Fig. 3.

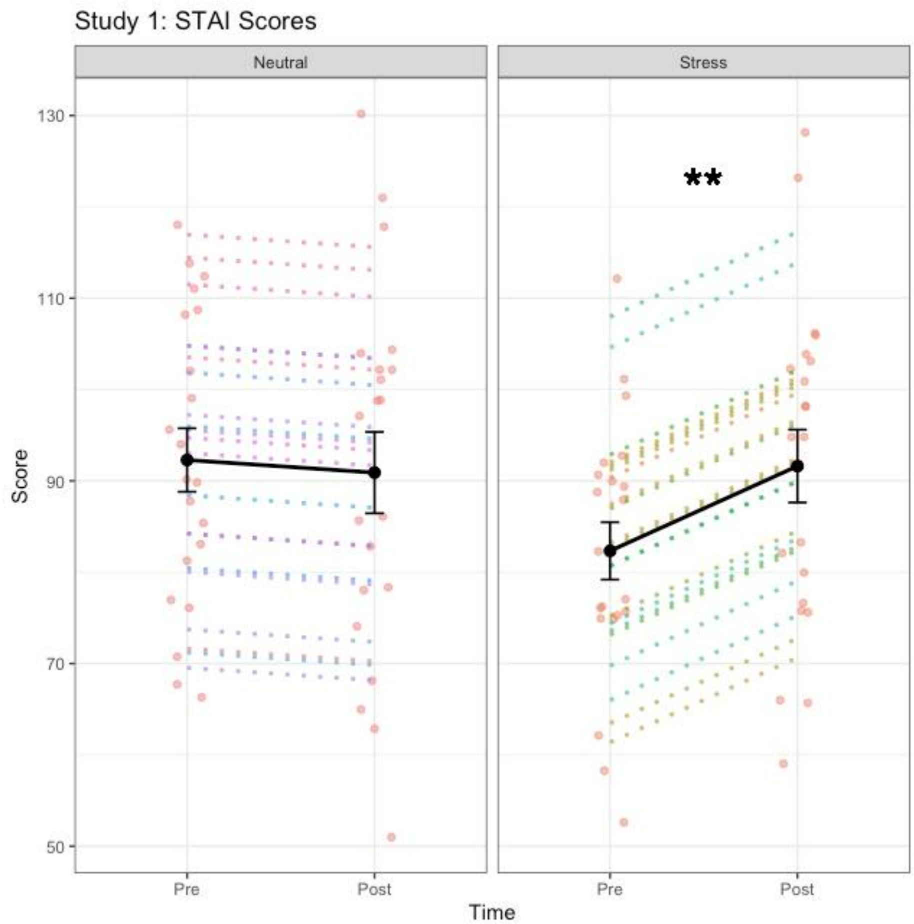

Fig. 3. ***STAI scores for Study 1.*** *The plot illustrates changes in scores over time (Pre and Post) for each condition (Neutral and Stress) using raw data points and model predictions. STAI scores are represented on the y-axis and the x-axis represents time points. Separate panels are used to distinguish each condition. Raw data points are jittered and plotted using semi-transparent dots where each point corresponds to an observed participant's STAI score. Dotted lines show model predictions for each participant to depict individual trajectories with colour used to distinguish between participants. Black dots indicate the overall mean scores for each time point and error bars represent standard error (SE). Statistical significance is shown for the pre- and post-test STAI scores in the Stress condition. The notation ** denotes statistical significance at $p < 0.01$.*

2.2.2.3 The effect of stress on explicit SoA

A linear mixed-effects model (using Satterthwaite's method) was conducted to examine the effects of Condition (Stress vs. Control) and Time (Pre vs. Post) on self-reported SoA Scores. There was a statistically significant main effect of Delay (β = −0.94, t = -8.08, p < 0.001) wherein, overall, participants' self-reported SoA tended to decrease as temporal delay increased, giving the largest ratings of control at the 100 ms delay (M = 4.31, SE = 0.03), decreasing at the 400 ms delay (M = 3.56, SE = 0.04), and decreasing the furthest at the 700 ms delay (M = 2.98, SE = 0.04). This finding is consistent with the literature on SoA, wherein an increased time delay between an action and outcome corresponds with decreased perceptions of agency.

There was a statistically significant three-way interaction for Condition x Time x Delay (β = −0.04, t = -2.13, p = 0.03). To further explore this interaction, post-hoc comparisons (with degrees of freedom calculated using the Kenward-Roger method) were performed to compare temporal delays across each Condition and Time of measurement (pre- vs. post-test). The results showed a statistically significant effect for the 700 ms delay in the Stress condition ($t(56.5)$ = 2.33, p = 0.02); however, this effect did not survive Bonferroni correction (p = 0.14) when comparing pre-test SoA scores (M = 3.14, SE = 0.08, 95% CI [2.98, 3.31]) to post-test scores (M = 3.41, SE = 0.08, 95% CI [3.24, 3.57]). No other statistically significant effects were found (all ps > 0.05). Data is visualized in Fig. 4.

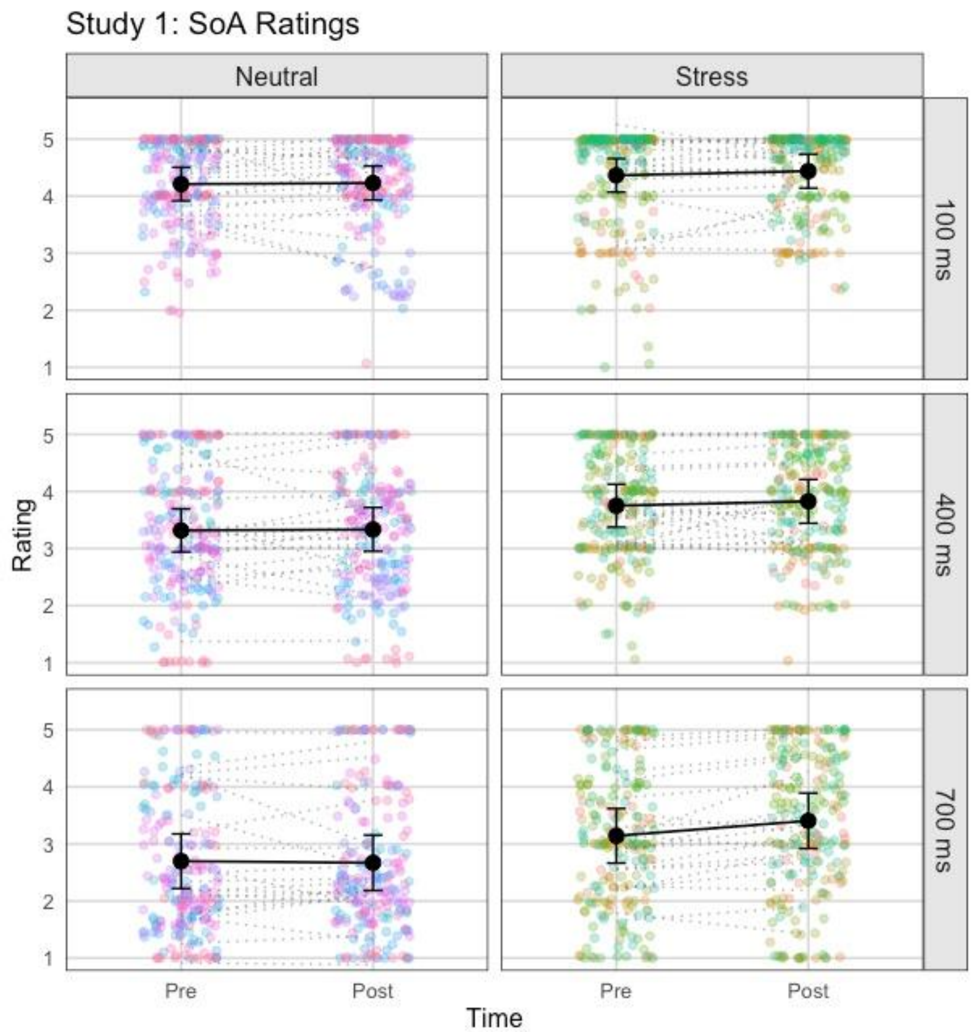

*Fig. 4. **SoA ratings by time, condition, and delay.** The plot shows participants' self-reported SoA ratings for each condition using raw data points and model predictions. SoA ratings are plotted on the y-axis. Time points are shown on the x-axis. The first panel represents participant pre- and post-test SoA ratings in the Neutral condition per each temporal delay. Participants' SoA ratings in the Stress condition are depicted in the second panel. Raw data points are jittered and plotted using semi-transparent dots where each point corresponds to an observed participant's SoA rating. The use of colour allows for clear distinction between conditions, with different colours within each condition representing individual participants. Dotted lines*

show model predictions for each participant to depict individual trajectories. Black dots indicate the overall mean scores for each time point and error bars represent SE.

Additionally, to estimate the power for our obtained sample size, we conducted a post hoc, simulation-based sensitivity power analysis using 2,000 simulated datasets based on our sample size of 42 participants (Kumle et al., 2021). The results indicated that a sample of N = 42 would provide a power of approximately 0.36 to detect the effect of a linear mixed-effects model with a significance criterion of α = 0.05. Limitations regarding the relatively low statistical power for this study are addressed in the General Discussion (Section 3).

2.2.3 Discussion

Study 1 explored the effect of stress on participants' self-reported SoA. The results of data analyses did not find any significant differences in SoA when comparing the Stress and Neutral conditions. While the analyses did reveal a decrease in participant agency scores when comparing the pre- and post-test measures of the 700 ms delay in the Stress condition, this finding was very weak and did not survive correction for multiple comparisons.

Given that this study employed a Likert-style self-report measure of SoA, it is possible that our results were influenced by participant biases and/or subjective interpretation (Wen & Imamizu, 2022). Thus, to provide a more comprehensive understanding of the relationship between stress and SoA, we conducted an additional study that follows essentially the same protocol as Study 1 but uses the implicit method of IB to assess SoA.

2.3 Study 2: Implicit SoA

2.3.1 Methods

2.3.1.1 Participants

Similar to Study 1, data for this study was collected over a period of one semester (four months). In total, 48 undergraduate psychology students were recruited from McMaster University. Two participants were excluded for failing to complete the study therefore, data from 46 participants (33 female, 12 male, one non-binary; M_{age} = 18.18, SD_{age} = 0.81) were included in the final analyses. All participants reported having normal or corrected-to-normal vision and hearing. Individuals with a current or previous diagnosis of major depressive disorder, bipolar disorder, generalized anxiety disorder, post-traumatic stress disorder, or head injury were excluded from this study. Participants were remunerated course credits (0.5 credits per 30 min) for their participation.

2.3.1.2 Materials: STAI, TSST, and TSST-placebo

The materials for Study 2 were identical to those used in Study 1. To measure stress, we administered the STAI before and after participants engaged in the study (Spielberger et al., 1971). To induce stress, participants underwent the TSST

(Kirschbaum et al., 1993). Participants in the control condition completed the TSST-placebo, which is designed to resemble the TSST without eliciting a stress response. Further details regarding the materials used in Study 2 can be found in Section 2.1.2. (Materials) of Study 1.

2.3.1.3 Experimental design

All study procedures were identical to Study 1, with the only difference being the measure used to index SoA. This study used a 2 (Condition: Stress, Neutral) x 2 (Time: Pre, Post) x 3 (Delay: 100, 400 700 ms) mixed design, with Condition as the between-subjects factor and Time and Delay being within-subjects.

The experimental task was developed using PsychoPy (v.2023.2.2) and deployed on a 15.6″ Dell Inspiron laptop. Participants were required to wear headphones for the duration of this task with the volume set to a standard of 70 dB. At the presentation of a fixation cross, participants were instructed to press the spacebar. At the time of the keypress, a tone was played after a randomized delay of either 100, 400, or 700 ms (see Fig. 5). Following the presentation of the tone, participants were asked to estimate the time interval in milliseconds between the keypress (action) and hearing the tone (outcome) by entering a number between 1 and 1000.

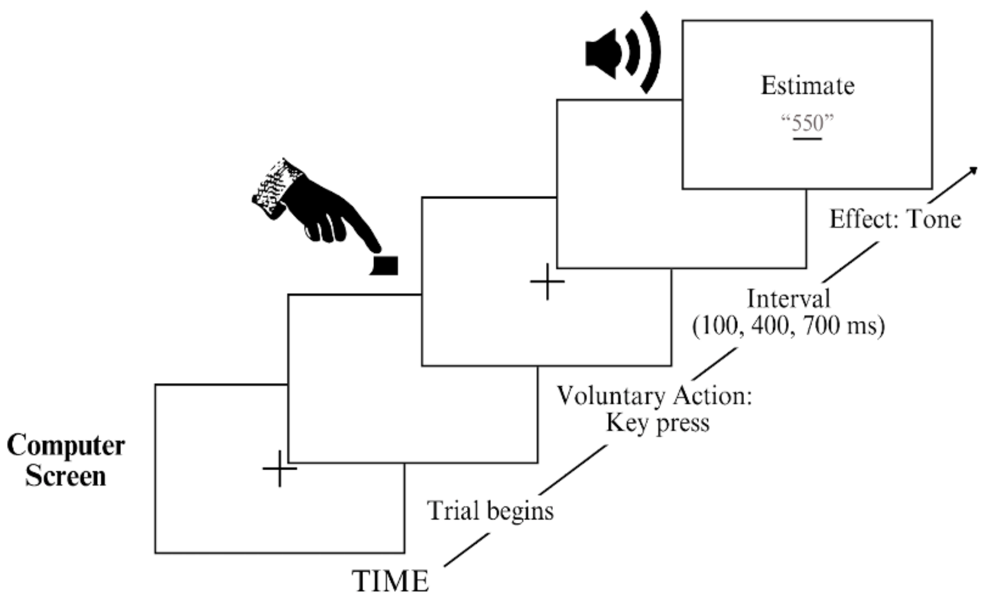

*Fig. 5. **The IB task.** At the presentation of a fixation cross, participants pressed the spacebar on a keyboard. At the onset of the keypress, a tone was presented at a randomized delay of either 100, 400, or 700 ms. Participants were then instructed to estimate the time interval between pressing the key and hearing the tone by entering a number between 1 and 1000.*

2.3.1.4 Procedure

The procedure for Study 2 was similar to Study 1 with the exception of the dependent variable being assessed (see Fig. 6). Participants were individually invited to the research laboratory where they received study information and were asked to indicate consent. Before beginning the study, participants completed a short demographics survey followed by the 40-item STAI embedded within 20 filler questions. Participants then completed three practice trials of the IB task, followed by 30 study trials. Participants were randomly selected to engage in either the experimental (Stress; *N* = 23) or the control (Neutral; *N* = 23) condition. Participants in the Stress condition underwent the TSST, which involved the job interview preparation phase (5 mins), the interview phase (5 mins), and the challenging verbal arithmetic challenge (5 mins). In the Neutral condition, participants underwent the TSST-placebo, which included the talk preparation phase (5 mins), the talk phase (5 mins), and the simple verbal arithmetic task (5 mins). Participants then completed the post-test IB task followed by the 40-item STAI embedded within additional filler questions. At the end of the study, participants were debriefed, remunerated, and thanked for their time. Participants in the Stress condition watched a three-minute mood-boosting video before departing the laboratory. The duration of each study was approximately one hour. For more detailed information regarding the study procedure, please refer to the Procedure Section (2.1.4.) of Study 1.

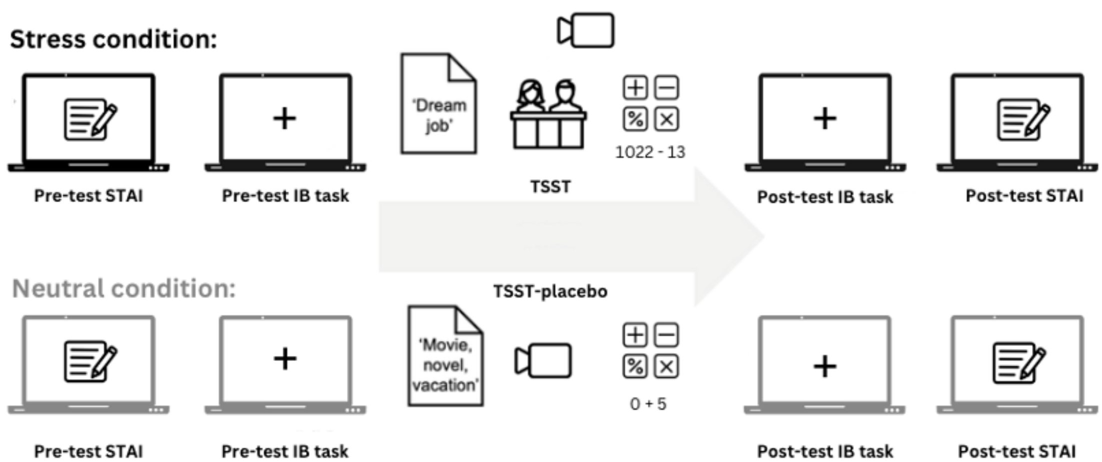

Fig. 6. ***Depiction of the experimental procedure of Study 2.*** *Row one depicts the experimental (Stress) condition where participants engaged in the pre-test STAI survey and IB task, followed by the TSST. Finally, participants completed a post-test IB task and STAI survey. Row two depicts the control (Neutral) condition where participants engaged in the pre-test STAI survey and IB task, followed by the TSST-placebo. Finally, participants completed a post-test IB task and STAI survey.*

2.3.2 Results

2.3.2.1 Data analysis plan

Data processing, visualization, and analyses were conducted using R v.4.4.2 (R Core Team, 2024) with R packages tidyverse (Wickham et al., 2019), lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), emmeans (Lenth, 2024), and ggplot2 (Wickham, 2016). A linear mixed-effects model was also used to analyze the effectiveness of the TSST in inducing stress. This model was fit using the following structure:

$$\text{Score} \sim \text{Condition} * \text{Time} + (1 \mid \text{ID})$$

Condition, Time, and their interaction were included as fixed effects with random slopes and intercepts for each participant (ID).

A linear mixed-effects model was then used to explore the effects of stress on participants' interval estimates. The model was fit using the lme4 package in R with the following structure:

$$\text{Estimates} \sim \text{Condition} * \text{Time} * \text{Delay} + (\text{Time} + \text{Delay} \mid \text{ID})$$

Fixed effects for this model were included for Condition (Stress vs. Neutral), Time (pre- vs. post-test), Delay (100, 400, 700 ms), and their interaction. Random intercepts and slopes were included for Time and Delay across participants (ID). Post-hoc comparisons for both models were conducted using the emmeans package in R.

2.3.2.2 Effectiveness of the stress manipulation (TSST)

A linear mixed-effects model (Satterthwaite's method) was conducted to examine the effects of Condition (Stress vs. Control) and Time (Pre vs. Post) on participants' STAI Scores. Cronbach's alphas for the 40-item STAI were 0.94 (pre-test) and 0.95 (post-test), indicating excellent internal consistency (Cronbach, 1951). There was no statistically significant main effect of Condition ($\beta = 3.32$, $t = 0.57$, $p = 0.57$) or Time ($\beta = 0.78$, $t = 0.31$, $p = 0.76$) meaning, in general, STAI scores did not significantly differ between conditions or over time. Importantly though, there was a statistically significant interaction between Condition (Stress vs. Control) and Time (Pre vs. Post) indicating that the change in STAI scores from pre- to post-test is dependent on whether participants were in the Stress or Neutral condition ($\beta = 11.17$, $t = 3.05$, $p = 0.004$).

Post hoc comparisons (Kenward-Roger, using the Bonferroni method for adjustments) revealed a statistically significant difference between the pre- and post-test STAI scores in the Stress condition ($t(43) = -4.56$, $p < 0.001$), wherein participants' stress scores were significantly lower at the pre-test ($M = 88.41$, $SE = 4.13$, 95% CI [80.11, 96.7]) than the post-test ($M = 100.36$, $SE = 4.13$, 95% CI [92.07, 108.66]). There was no statistically significant difference in participants' pre- ($M = 85.09$, $SE = 4.04$, 95% CI [76.97, 93.2]) and post-test ($M = 85.87$, $SE = 4.04$, 95% CI [77.76, 93.98]) STAI scores for the Neutral condition, indicating that the TSST-placebo was effective in providing a control condition that was equivalent to the TSST without causing stress to participants. Data is visualized in Fig. 7.

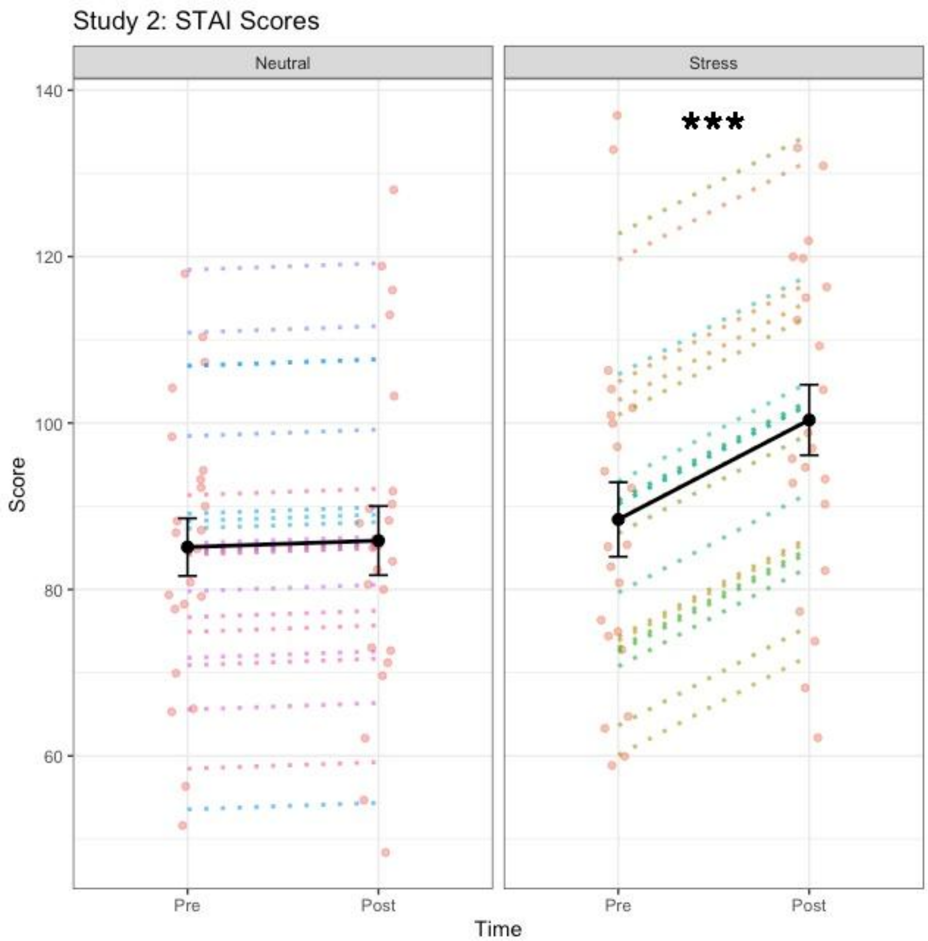

Fig. 7. ***Comparison of STAI scores per condition.*** *The plot shows changes in stress scores for pre- and post-test timepoints for each condition (Neutral and Stress). The plot uses both raw data points and model predictions. STAI scores are shown on the y-axis and the x-axis indicates Time. To show comparison across groups, conditions are listed in separate panels. Raw data points are jittered and plotted using semi-transparent dots wherein each point corresponds to an observed participant's STAI score. Dotted lines show model predictions for each participant to depict individual trajectories with colour used to distinguish between participants. Black dots indicate the overall mean scores for each time point and error bars represent SE. Statistical significance is shown for the pre- and post-test STAI scores in the Stress condition. The notation *** denotes statistical significance at p < 0.001.*

2.3.2.3 The effect of stress on implicit SoA

A linear mixed-effects model (Satterthwaite's method) was conducted to examine the effects of Condition (Stress vs. Control), Time (Pre vs. Post), and temporal Delay (100, 400, 700 ms) on participants' interval estimates. There was a statistically significant main effect of Delay (β = 282.11, t = 13.28, p < 0.001) wherein, overall, participants' interval estimates tended to be the smallest at the 100 ms delay (M = 175, SE = 5.84), increasing at the 400 ms delay (M = 366, SE = 6.54), and increasing further at the 700 ms delay (M = 575, SE = 7.83). There was a statistically significant main effect for Condition (β = 33.56, t = 2.03, p = 0.05), a statistically significant interaction for Time x Delay (β = -34.87, t = -7.47, p < 0.001), and a statistically significant three-way interaction between Condition x Time x Delay (β = 17.84, t = -3.82, p < 0.001).

To further explore these findings, post-hoc comparisons were performed (with degrees of freedom calculated using the Kenward-Roger method) from the emmeans package in R. Like Study 1, the results show a significant effect for the 700 ms delay in the Stress condition however, in this study, the effect survives Bonferroni corrections ($t(67.6) = -4.1$, $p < 0.001$). This finding indicates a statistically significant difference between the pre- (M = 584, SE = 34.5, 95% CI [514.6, 654]) and post-test (M = 485, SE = 36.7, 95% CI [411.1, 559]) interval estimates in the Stress condition for the 700 ms delay. This suggests that, after experiencing stress, participants' SoA is increased only for outcomes that occur 700 ms after the produced action. No other significant differences were found (all ps > 0.05). Data is visualized in Fig. 8.

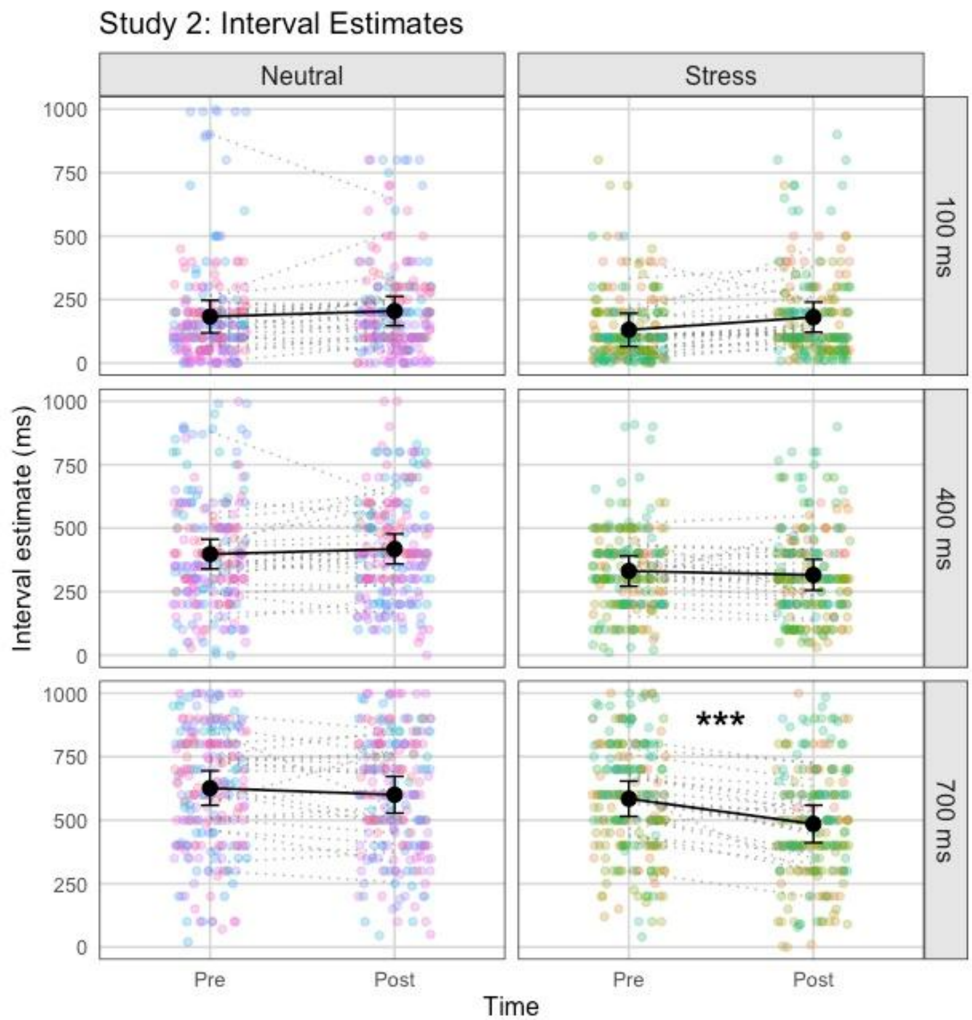

Fig. 8. ***Interval estimates by time, condition, and delay.*** *The plot shows a comparison of participants' interval estimates from the IB task for each condition using raw data points and model predictions. Interval estimates (ms) are plotted on the y-axis. Time points are shown on the x-axis. The first panel represents participant pre- and post-test interval estimates for the Neutral condition per each temporal delay. Participants' interval estimates in the Stress condition are depicted in the second panel. Raw data points are jittered and plotted using semi-transparent dots where each point corresponds to an observed participant's interval estimate. The use of colour allows for clear distinction between conditions, with different colours within each condition representing individual participants. Dotted lines show model predictions for each participant to depict individual trajectories. Black dots indicate the overall mean scores for each time point*

*and error bars represent SE. Statistical significance is shown for the pre- and post-test scores in the Stress condition for the 700 ms delay. The notation *** denotes statistical significance at $p < 0.001$.*

Additionally, to estimate the statistical power associated with our obtained sample size, we conducted a post hoc, simulation-based sensitivity power analysis using 2,000 simulated datasets based on our sample of 48 participants. (Kumle et al., 2021). The analysis showed that a sample size of N = 48 would yield approximately 0.87 power to detect an effect using a linear mixed-effects model using a significance level of $\alpha = 0.05$.

2.3.3 Discussion

The results of Study 2 provide compelling consistencies with the trend for explicit agency ratings observed in Study 1, wherein participant agency scores were shown to increase at the 700 ms temporal delay for the Stress condition. Unlike the first study, data analyses conducted in Study 2 reveal that this difference is indeed statistically significant. Importantly, and as anticipated, participant STAI scores were shown to differ significantly between the pre- and post-test measures for the Stress condition. Thus, the implementation of both the TSST and the TSST-placebo were successful in inducing stress and maintaining neutral mood states, respectively. Further considerations regarding the differences in SoA at the 700 ms temporal delay are discussed below.

2.4 General Discussion

Across two studies, similar protocols were administered to assess the effects of stress using explicit (self-report) and implicit (IB) measures of SoA. It was consistently found that participants undergoing the Stress condition reported significantly higher stress levels than participants in the Neutral condition, confirming that our stress manipulations were effective. In Study 1 (explicit), participants in the Stress condition exhibited an increased SoA for action outcomes in the 700 ms delay, although this finding did not survive correction for multiple comparisons. In Study 2 (implicit), a robust effect was found, indicating a highly significant increase in SoA for the 700 ms delay condition. No other significant effects were found. Previous research investigating the relationship between stress and SoA has been somewhat inconsistent, and our results provide additional evidence about how stress could affect the critical human experience of agency. Intriguingly, the results of the current studies appear to contradict one recent study exploring stress and SoA, which suggested that stress has a negative effect on implicit SoA (Chu et al., 2023). Taken together with the current results, it seems that the relationship between stress and SoA may be quite nuanced.

Previous research has shown that stressful situations can produce time distortion effects—for example, in a study exploring the effects of stress on time perception, researchers found that participants undergoing acute psychosocial stress produced using the TSST experienced stimuli as lasting longer in time than its objective interval (Hedger et al., 2017). This effect, referred to as time dilation, has been shown consistently in the literature wherein individuals often experience time slowing down as a response to negative or threatening stimuli (e.g., Droit-Volet & Meck, 2007). However, events inducing anxiogenic states have been found to have the opposite effect: Experimentally inducing anxiety causes participants to consistently underestimate various temporal intervals (Sarigiannidis et al., 2020). Explanations for this discrepancy suggest that the time dilation effect is present only for events producing an imminent threat—that is, events that induce fear rather than anxiety (Davis et al., 2010). Given that we assessed the effects of the stress manipulation (TSST) using the STAI and found increased STAI scores post-manipulation, our results could be considered somewhat consistent with this previously reported pattern. However, because we only observed such an effect at the longest action-effect delay of 700 ms and not for prior delays, the notion that our observed effect is a general effect on time perception is unlikely. It is also difficult to fully interpret the current findings in the light of previous work on stress and time perception as the time intervals used in past work are often much longer than the intervals used in IB experiments (e.g., short intervals are usually classed as around the 1 s mark which is longer than the longest interval used here, Droit-Volet & Meck, 2007).

What then might explain the differential effect of stress on IB for the shorter versus longer action-effect intervals used in this study? Although the quantitative difference between 100, 400, and 700 ms action-effect delays may seem small, this distinction appears to impact cognitive processes involved in IB. Indeed, a robust finding in the IB literature is that binding is strong for short action effect intervals and weakens for longer time delays, such as the 700 ms for which we found an effect here (see Moore & Obhi, 2012 for a review; Malik et al., 2022). Correspondingly, in a study by Wen and colleagues (2015), participants reported diminishing levels of agentic experience as action-effect intervals increased (from 0-1000 ms). Thus, one possibility is that agency (and, more generally, the perception of causation) is strongly driven by temporal contiguity of actions and effects in short interval scenarios, leaving little room for a potential moderator like stress to exert an effect. In contrast, for longer intervals where SoA is usually weaker (i.e., lower IB and lower explicit agency ratings), stress exerts an effect to essentially boost agency. Such a "stress-enabled agency boost" for longer action-effect intervals could indicate that the stress experienced by participants in our study activated a sympathetic nervous system response and put them into a more agentic mode that accompanies a fight-or-flight response. Indeed, prior work has confirmed that the TSST reliably activates the sympathetic adrenal medullary system that supports a fight-flight state (see Allen et al., 2014 for a comprehensive review). In this respect, we speculate that in certain situations, the 700 ms effect of stress that we observed could be in line with the possible behavioural time scale of a fight-or-flight response, compared to the shorter intervals we employed. However, this idea necessitates further investigation, and we make no strong claims here.

Our result is intriguing in the context of the limited prior work on the relationship between stress and IB reported by Chu and colleagues (2023). Those authors used a very similar approach to the one used here but found a decrease in binding after the stress manipulation. However, since they did not include the action-effect delay in their analysis, it is difficult to directly compare the two sets of results. That said, it is well established that there exists an inverted U relationship between stress (and the resulting increase in arousal) and performance (e.g., Martens and Landers, 1970; Welford, 1973; Yerkes and Dodson, 1908). It could be the case that our manipulation pushed participants into an optimal state of performance, which may have had corresponding effects on their sense of agency. This aligns with the concept of eustress, where moderate stress enhances performance and agency. However, as stress intensity increases, it may transition into distress, potentially leading to a loss of agency, particularly in more extreme cases such as traumatic events (Adrien et al., 2024). Further increases in stress could then result in a decrease in agency, as performance deteriorates according to the inverted U relationship. Further work in which the level of stress is parametrically varied and the effects on agency are assessed will be needed to explore this possibility further. For now, the finding of opposite patterns of stress on IB provides fertile ground for a more robust future interrogation of the effects of psychosocial (and other forms of) stress on IB.

One important limitation of our work is that we are unable to strictly rule out that our effect is due to an effect on general time perception as opposed to an effect on agency per se. Future work should consider employing an additional non-action time perception task as a control. Our available resources and time did not allow such a condition to be added. Additionally, the results of a post hoc sensitivity power analysis indicated that the statistical power in Study 1 was relatively low at 0.36 for $N = 42$, which may have reduced the likelihood of detecting smaller effect sizes. Given the substantial difference in power between both studies despite similar sample sizes, it is possible that the SoA measure used for Study 1 was not sensitive enough, given that it relied on a relatively narrow Likert scale with input options ranging from 1 to 5. Future research should consider expanding the range of scales implemented in explicit SoA measures to enhance the detection of effects. That said, the correspondence between our weak effect on explicit agency and our relatively strong effect on binding provides an interesting picture of the potential relationship between stress and binding. Further factors, such as gender and the use of coping strategies, might mediate the impact of stress on SoA in this study. The majority of the participants identified as female, who are often known to respond to psychosocial stressors differently than males, potentially influencing SoA (Knowles & Olatunji, 2020). Moreover, experiences with socially ascribed gender roles may influence the baseline level of SoA in females relative to males (Brancazio, 2019). Practicing coping strategies that emphasize a sense of control is often better able to protect against the negative effects of stress (Dijkstra & Homan, 2016). Given that our participant population were undergraduate students and a portion of the data collection process was conducted during exam season, it is possible that participants were actively engaging in coping strategies to protect against a well-known high period of stress for students.

The current study and the study done by Stern and colleagues (2020) both excluded participants with a history of mood disorders, unlike the study by Chu and colleagues (2023). Individuals with mood disorders, such as major depressive disorder and anxiety disorders, may experience a different baseline SoA compared to individuals without disorders (see Obhi et al., 2013; Mehta et al., 2023) and may respond differently to stress (Narvaez Linares et al., 2020). Further, the TSST is a very specific stress manipulation—this protocol induces psychosocial stress specifically, as caused by having the interviewers elicit feelings of uncontrollability and threat to the participant's social self and self-esteem (Dickerson & Kemeny, 2004). The neutral expressions on the interviewers' faces, which do not indicate whether a participant is performing well or poorly, lead to a feeling of uncontrollability. Participant self-esteem is further threatened by the social evaluation presented by the interviewers (Het et al., 2009). Inducing different forms of stress, such as cognitive or work-related stressors, may result in differential effects on SoA than what was observed in this report.

In sum, across two experiments we observed a pattern of data that suggests a potential agency-boosting effect of psychosocial stress at 700 ms action effect intervals. We suggest that such an effect may correspond to the activation of the fight-or-flight response and that the existence of the effect for the 700 ms action effect interval could be consistent with the behaviourally relevant timescale of potential fight-or-flight related actions in certain contexts, although this idea needs further investigation. Our findings underscore the critical role of temporal factors in shaping processes related to SoA and stress responses. Incorporating 700 ms delays in training simulations, such as those used in medical and aviation exercises, could enhance SoA and optimize perceived control, making it particularly beneficial in high-stress training environments where realism and a strong SoA are essential. However, the relationship between stress and agency is far from well understood and we note the contradictory findings of this study with one previous study that also used IB to index agency. We therefore strongly encourage researchers to further investigate the relationship between stress and SoA, particularly in how it pertains to clinical populations given that the ramifications of stress on agency in a general population are likely to be different (Zubin & Spring, 1977).

References

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Chapter 3

Effects of instruction source on the sense of agency: Humans vs. artificial agents

The content of this chapter is presented in publishable format and in preparation for submission to a scholarly journal.

Edwards, S. & Obhi, S. S. (Forthcoming). Effects of instruction source on the sense of agency: Humans vs. artificial agents.

Preface

The 21st century so far has been largely characterized by advances in technology that have reshaped human interaction. Today, humans are no longer confined to engaging in social interactions exclusively with other humans—technologies powered by artificial intelligence (AI) can enable machines the ability to interact with humans in dynamic and meaningful ways (Zimmerman et al., 2023; Kusal et al., 2022; Brandtzaeg et al., 2022; Croes & Antheunis, 2021). AI systems use artificial neural networks that give machines the ability to 'understand' user inputs. This enables technology to simulate cognitive processes related to natural human cognition and engage in communication, such as responding to user input or engaging in text-based conversation with humans (Lv, 2023; Shubhendu & Vijay, 2013). As AI becomes more embedded in day-to-day life, humans are increasingly confronted with the novel experience of interacting with non-human agents who engage in human-like ways. In some cases, these agents replace the need for human-human interaction altogether—for example, many are familiar with the common experience of conversing with customer service chatbots, created to help individuals solve issues without needing to interact with a human customer support agent.

Intriguingly, the use of AI is rapidly increasing in contexts that involve instruction delivery. Given its ability to assist humans in completing tasks more efficiently, many industries are adopting AI to replace roles traditionally played by humans, often with the intention of reducing service costs and human labour (Kim et al., 2021; Adamopoulou & Moussiades, 2020). For instance, AI in healthcare is used to analyze large datasets and detect patterns, providing users with data-driven recommendations (Jiang et al., 2017). AI chatbots, such as Ada, analyze the input of user data to identify patient symptoms and provide assessments, potentially influencing critical decisions made by individuals seeking medical advice (Jungmann et al., 2019).

Beyond this, AI continues to span a wide array of human endeavors, including fields such as the military, where it can enhance strategic decision-making, surveillance and autonomous systems (e.g., Szabadföldi, 2021; Raska & Bitzinger, 2023); sports, where it can optimize performance analysis, injury prevention and fan engagement (e.g., Novatchkov & Baca, 2013; Chidambaram et al., 2022; Xu & Baghaei 2025); healthcare, for disease diagnosis, personalized treatment and drug discovery (e.g., Meskó & Topol, 2023; Fleming, 2018); education, in personalized learning and administrative support (e.g., Pataranutaporn et al., 2021; Igbokwe, 2023); finance, through fraud detection, algorithmic trading and risk assessment (e.g., Cao, 2022); and entertainment, where AI drives content recommendations, virtual reality experiences and creative tools (e.g., Hallur et al, 2021).

This growing integration of AI into social and instructional contexts raises many critical questions about the human experience during interactions with artificial agents. One of these questions include its relation to SoA, or the feeling of control over one's actions. Despite the large influence and increasing prevalence of AI in roles that influence human action, there is a paucity of research that explores the effect of technology-driven instruction on the SoA. The following study in this thesis seeks to address this important gap by exploring the experience of agency when individuals receive instruction from artificial agents.

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Effects of instruction source on the sense of agency: Humans vs. artificial agents

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Abstract

The sense of agency (SoA)—the experience of being in control of one's own actions and outcomes—is a fundamental aspect of daily life. Prior research shows that SoA can be disturbed when actions are externally instructed rather than voluntarily initiated, yet the role of the instructing agent in shaping this effect remains largely underexplored. As artificial agents become more embedded in everyday interactions, their potential to influence human action raises important questions about the experience of agency. Across two studies, we investigated how action instructions delivered by a human versus an on-screen chatbot influence both implicit (intentional binding; IB) and explicit (self-reported control) measures of agency. The results of Study 1 (implicit) showed that IB was strongest in the free choice condition, wherein participants' actions were of their own volition compared to actions conducted under external instruction. Notably, binding was significantly reduced when actions were directed by a chatbot compared to the free choice condition. Similarly, the results of Study 2 (explicit) showed that self-reported control ratings were the highest in the free choice condition and decreased significantly when comparing the free choice condition with both the human instruction and agent instruction conditions. Both studies observed a significant linear trend in which interval estimates and control ratings for human-instructed actions were numerically between those for free choice and agent instruction. The results of this study reveal important information about how people respond to human vs. technology-driven instruction.

Keywords: *Sense of agency (SoA), artificial agents, action instruction, temporal binding, implicit, explicit*

3.1 Introduction

The sense of agency (SoA), the perception of being in control over one's own actions and their consequences, is a core component of the human experience (Haggard & Tsakiris, 2009). For healthy individuals, the SoA typically arises for voluntarily performed actions, such as intentionally pressing a button to change the television channel. Often, these voluntary actions can be accompanied by feelings where one feels ass though they are indeed the author of one's own actions. In contrast, SoA tends to diminish for involuntarily performed actions—for example, if someone else physically guides a person's finger to press a button, they are more likely to feel like the action was externally determined and not caused by them. This SoA plays a crucial role in distinguishing between self-generated actions and those produced by others (Haggard & Tsakiris, 2009; Moore, 2016). Notably, SoA has been associated with feelings of responsibility, wherein a stronger SoA often corresponds to a greater sense of responsibility for the outcomes of one's actions (Frith, 2014; Caspar et al., 2021; Moore, 2016).

Much of the previous research exploring the SoA has employed either implicit or explicit methods to quantify it in laboratory settings. Explicit methods typically involve asking participants to directly evaluate their perceived amount of control or causation over a task, often using Likert-style scales. On the other hand, implicit measures infer agency through indirect indicators, such as intentional binding (IB) observed during behavioural tasks. IB refers to the subjective compression of time between a voluntary action and its corresponding outcome (Haggard et al., 2002). This temporal compression is associated with higher levels of SoA, wherein individuals who perform an action voluntarily tend to perceive a shorter interval of time between their action and the resulting effect. Conversely, when actions are involuntary, the SoA is generally reduced and the perceived time between an action and its outcome is experienced as being larger than its objective interval.

Several experiments have shown that SoA can be disrupted when actions are carried out under external instruction rather than initiated independently. For example, in tasks where participants are instructed to make key presses under forced choice conditions, they generally exhibit reduced temporal binding (i.e., reduced SoA) compared to conditions where key presses are freely chosen (Barlas et al., 2018; Barlas, 2019; Huang et al., 2024; Zanatto et al., 2023a). Overall, these findings suggest that voluntary action can enhance the perceived temporal proximity between an action and its outcome, reinforcing a stronger sense of control. In contrast, instructed actions may weaken this temporal association, reflecting a diminished experience of agency. Additionally, research using explicit methods for quantifying SoA has exhibited similar results, wherein instructed conditions generally lead to reductions in participants' self-reported feelings of control compared to a free choice condition (Barlas et al., 2018; Barlas, 2019; Shwarz et al., 2019). This effect on both implicitly and explicitly measured SoA has also been observed for actions that are carried out under coercion (Caspar et al., 2016; Caspar et al., 2018; Akyüz et al. 2024), and it tends to be strongest when the instructed action has a negatively valenced outcome (Niu et al., 2023).

However, some studies have reported findings that challenge these results, showing that action choice (forced vs. freely determined) does not consistently impact temporal binding (see Shwarz et al., 2019; Antusch et al., 2021). Additionally, the effects of action instruction on implicit SoA are further nuanced in contexts involving sequential actions (Muth et al., 2022), or when participants are instructed specifically on what action to perform, whether to act, or when to act (Zanatto et al., 2023b). Taken together, this research highlights an important role of instruction in shaping some aspects of agency, though its overall effects on implicit SoA remain generally unclear. In contrast, explicit measures of SoA suggest a more consistent pattern, wherein perceived SoA is regularly diminished when action instructions are delivered by external agents.

Yet, the question of how the specific type of instructing agent can influence both implicit and explicit dimensions of agency is largely underexplored. To date, research on action instruction has primarily focused on instruction delivery by humans, robots, or on-screen textual and visual cues in general. Barlas (2019) was among the first to directly compare the effects of different instructing agents on the SoA, evaluating human-delivered instructions to those delivered by both autonomous and non-autonomous robots. Across two experiments, it was consistently found that receiving action instructions reduced both explicit (control ratings) and implicit (IB) measures of SoA compared to free choice conditions. However, no significant differences emerged between the types of instructing agents specifically—all conditions including action instruction were found to similarly diminish SoA, and the perceived autonomy of the robot had no significant influence on participants' control ratings or binding results.

At the time of writing this report, no studies have yet to directly explore the effects of instruction delivered by online artificial agents within the same experimental framework. This gap is increasingly relevant as artificial agents (i.e., on-screen chatbots, voice assistants, and embodied virtual avatars) become increasingly common in modern routines. Many artificial agents are powered by artificial intelligence (AI) allowing them to engage with users in dynamic and meaningful ways (see Zimmerman et al., 2023; Kusal et al., 2022; Brandtzaeg et al., 2022; Croes & Antheunis, 2021). In some cases, this includes the ability to influence human actions—for example, across various domains such as healthcare, customer service, and workplace environments, artificial agents can be used to deliver instructions that influence users' decisions, guide actions, and mediate task performance (Jiang et al., 2017; Jungmann et al., 2019; Adamopoulou & Moussiades, 2020; Brandtzaeg & Følstad, 2017). In some cases, artificial agents can replace human-human interaction altogether—for example, customer service chatbots are designed to provide automated customer support without the need for human intervention (Nicolescu & Tudorache, 2022). As artificial agents become more socially and functionally embedded in daily life, understanding their specific influence on the SoA when providing action instructions is both theoretically and practically significant. To address this gap, we investigated how action instructions delivered by a human versus an artificial agent (in the context of an on-screen chatbot) affect SoA using both implicit (IB; Study 1) and explicit (self-report; Study 2) measures.

Given the results of previous research on action instruction and the SoA, we expect to find greater binding and control ratings (i.e., increased SoA) for actions that are freely selected compared to those that are externally instructed either by another human or an on-screen chatbot. Additionally, we anticipate finding a difference in SoA based on whether instructions are delivered by a human or an artificial agent. Despite the study by Barlas (2019) finding no differences between human- and robot-delivered instructions, the role of the robot's physical presence in that null effect is unclear. Given that the robot used in the study shared the same physical space as participants, its social salience may have minimized differences in perceived agency irrespective of whether or not it was perceived as being autonomous or non-autonomous. In contrast, the on-screen chatbot used in the present study exists only in a virtual environment, which may reduce its social influence irrespective of its perceived autonomy and allow for participants to experience a greater retention of agency. This aligns with diffusion of agency theories, which propose that individuals experience reduced personal authorship when actions are shared with other agents, including humans and computers, that inhabit a shared physical environment (Bandura, 1999; Obhi & Hall, 2011). Therefore, we hypothesize that actions instructed by artificial agents will cause greater binding and increased control ratings compared to actions instructed by humans.

3.2 Study 1: Action instruction effects on IB

3.2.1 Methods

3.2.1.1 Participants

The sample size was determined a priori using G*Power 3.1 (Faul et al., 2009) which suggested 36 participants for a within-subjects experiment with three conditions to achieve a power of 0.90 with a medium effect size (f = 0.25, alpha = 0.05; Cohen, 1988). A total of 40 participants were recruited to account for potential dropouts. All participants completed the study; therefore, the full sample was included in the data analysis (N = 40, 29 female, M_{age} = 18.25, SD_{age} = 1). Participants consisted of first-year psychology students recruited from McMaster University and eligible participants were required to have normal or corrected to normal vision and hearing. 85% of participants reported being right-handed (N = 34). Individuals were remunerated 0.5 course credits for participating in the 30-minute study. The study was approved by the McMaster University Ethics Board and conducted in accordance with ethical guidelines of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.

3.2.1.2 Study materials and design

This study used a within-subjects design with action instruction (Free Choice, Human Instruction and Agent Instruction) as the main experimental factor. Study conditions were counterbalanced using the Latin Squares method (Grant, 1948). The experiment was programmed using PsychoPy v2024.1.5 (Pierce et al., 2019) and administered on a ThinkCentre m910z Signature Edition computer (Intel Core i7-7700 CPU @ 3.60GHz, 64-bit) equipped with Windows 10 Pro (v.2009, OS 19045.4412). A 20-inch Lenovo desktop monitor (LEN-M910z-B) supported the experiment with a screen resolution set to 1920 x 1080 and a refresh rate of 60 Hz. Screen brightness was monitored and maintained at a consistent setting of maximum brightness, and the volume for each participant was set to a standard of 70 decibels. Participants navigated through the study using a wired Dell computer mouse (model MO56UOA) and entered responses via a Lenovo keyboard (model KU-0225).

To quantify SoA, we implemented an interval estimation (IE) task wherein participants were asked to directly estimate the temporal interval between an action and an effect. In this task, participants were required to press a key on the keyboard which would cause a tone to play. Two keys were designated as the 'action' keys for this study: the left key (z), which was defined on the keyboard using a round sticker marked with the letter 'L', and the right key (m), which was defined using a round sticker marked with the letter 'R'. After pressing a key, the tone was presented after a randomly assigned delay of either 100, 400, or 700 ms. Each delay occurred with equal frequency (16 times over the 48 experimental trials) and in a random order. After hearing the tone, participants were required to estimate the time interval in ms between when they pressed the key and when they heard the tone. The interval estimation was conducted on a sliding scale, wherein participants used the computer mouse to drag a slider on the screen and choose a number between 1 and 1000. The scale was marked numerically, beginning with a value of 1 at the leftmost position, followed by 100, and continuing in increments of 100 up to a maximum value of 1000 at the rightmost end. The slider, represented by a small circular marker, was positioned at the midpoint of the scale at the start of each trial estimation, corresponding to a value of 500. Above the scale a text prompt appeared for the practice trials only, which read: "Please estimate the time interval between when you pressed the key and when you heard the tone in MILLISECONDS. Remember, there are 1000 milliseconds in 1 second. Choose a number between 1 and 1000." During the study trials, no textual stimuli was present.

In the Agent Instruction condition, participants were provided with keypress instructions from an on-screen chatbot referred to as Cogito. Cogito's appearance was consistent with typical low human-likeness robotic chatbots: it featured a simplified, round head with minimalistic facial features (eyes and a mouth) and a small, animated body that hovered above the ground without visible legs. The body was rendered in light blue with a glossy, animatronic texture. On screen, Cogito appeared to float, gently bobbing up and down, and occasionally moved its arms in simple, gestural motions to accompany its verbal instructions. The verbal output used for Cogito was created using an online text-to-voice generator, and appeared slightly feminine while exhibiting mild synthetic qualities characteristic of AI-generated speech. The subtle feminine quality of the voice was selected to align with the Human Instruction condition, in which key instructions were delivered by a female experimenter. Cogito was programmed to deliver instructions to press the left and right keys to an equal extent. Thus, in total, the participant was instructed to press the left key 24 times and the right key 24 times in random order over the 48 experimental trials.

3.2.1.3 Procedure

On an individual basis, participants were invited to attend an in-lab study. After arriving to the research lab, participants received general information about the study and were asked to indicate their consent by signing a paper form. After consenting to participate, the experimenter provided verbal instructions about the study. Participants were then given the opportunity to ask any questions about the study before advancing to the study task. Each study condition was presented individually, with the presentation order determined using the Latin Squares method. Each condition began with specific on-screen instructions and consisted of six practice trials followed by 48 experimental trials (for a visual depiction of the study conditions, see Fig. 1).

In the Free Choice condition, participants were given the option to press either the left or right key upon their own volition and at their own desired pace to advance each trial. At the beginning of this condition, participants were provided with the following on-screen instructions: "In this part of the study, YOU will have the option to decide for yourself and choose which key to press." Participants would then advance to the start of each study trial by using the mouse to press a 'continue' button on the bottom of the screen. Each trial began with a fixation cross placed in the center of the screen accompanied by a text prompt that read, "Press either the LEFT or RIGHT key to hear a sound." Upon pressing a key, the trial would advance causing the fixation cross to disappear. After a random delay of either 100, 400, or 700 ms, a tone would play through the computer speaker. Participants would then input their interval estimations by using the mouse to drag a slide on a scale of 1-1000. After moving the slider, a small 'continue' button would appear at the bottom of the screen. Once participants used the mouse to click this button, the trial would repeat.

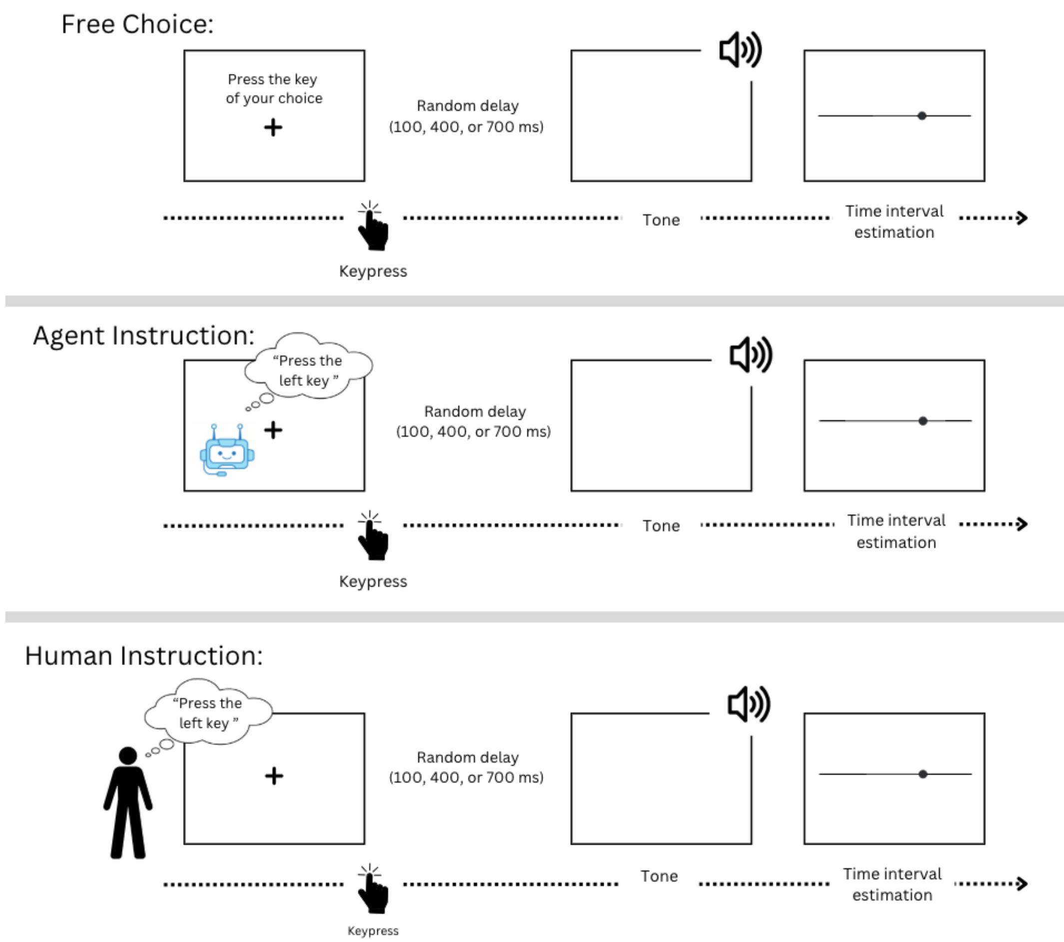

Fig. 1. **Depiction of the IE task and experimental conditions.** Each trial began with a fixation cross on the computer screen. Participants would freely decide which key to press in the Free Choice condition. In the following conditions, participants would be instructed which key to press by an on-screen chatbot (Agent Instruction condition) or the human experimenter in the room (Human Instruction condition). After a random delay (100, 400, or 700 ms), a tone would play. Participants would then enter their time interval estimation, and the trial would repeat.

In the Agent Instruction condition, participants were verbally instructed which key to press by an on-screen chatbot. For this condition, participants were provided with the following on-screen instructions: "In this part of the study, an AI CHATBOT will instruct you which key to press. It is important that you do not press any key before the AI chatbot instructs you which key to press." The chatbot, referred to as Cogito, appeared on the left side of the screen at the start of each trial. Additionally, a fixation cross was positioned in the center of the screen. Cogito provided verbal keypress instructions by directing participants to "Press the left/right key." After completing the keypress, the chatbot and fixation cross disappeared simultaneously. After a random delay (100, 400, or 700 ms) a tone would play. Participants would then complete the IE task using the sliding scale. Once completed, a 'continue' button appeared at the bottom of the screen which, when selected, would restart the trial.

In the Human Instruction condition, the experimenter in the room provided verbal keypress instructions ("Press the left/right key"). In this condition, the experimenter sat in a chair that was positioned to the right side of the participant. Like in the Agent Instruction condition, key instructions were delivered to an equal extent wherein participants were instructed to press the left key 24 times and the right key 24 times in random order. The condition began with the following on-screen instructions: "In this part of the study, the EXPERIMENTER will instruct you which key to press. It is important that you do not press any key before the experimenter instructs you which key to press." Each trial began with a fixation cross centered on the screen. The experimenter would then provide verbal keypress instructions by directing participants to "Press the left/right key." After participants pressed the corresponding key, the fixation cross disappeared and a tone would play following a random delay of either 100, 400, or 700 ms. A sliding scale would then appear on the screen and participants would provide their time interval estimation by choosing a value between 1-1000. Finally, a 'continue' button would appear at the bottom of the screen. The trial was repeated when participants used the computer mouse to select the button.

At the end of the study, participants completed a short demographics survey using the online survey tool LimeSurvey (LimeSurvey GmbH, n.d.). Participants were then debriefed, remunerated, and thanked for their time. The entire duration of the study was approximately 30 minutes.

3.2.2 Results

3.2.2.1 Data analysis

Data processing, visualization and analyses were conducted using R v.4.4.2 (R Core Team, 2024) with R packages dplyr (Wickham et al., 2023), tidyverse (Wickham et al., 2019), psych (Revelle, 2024), car (Fox & Weisberg, 2019), rstatix (Kassambara, 2023), and ggplot2 (Wickham, 2016). Normality testing was conducted using the Shapiro-Wilk test and equal variances were determined via the Bartlett test of homogeneity. A repeated-measures analysis of variance (rmANOVA) revealed a significant effect of condition on participants' interval estimates, $F(1.98, 77.30) = 4.06$, $p = .021$, $\eta^2 = .015$. Greenhouse-Geisser corrections were applied due to violations of sphericity.

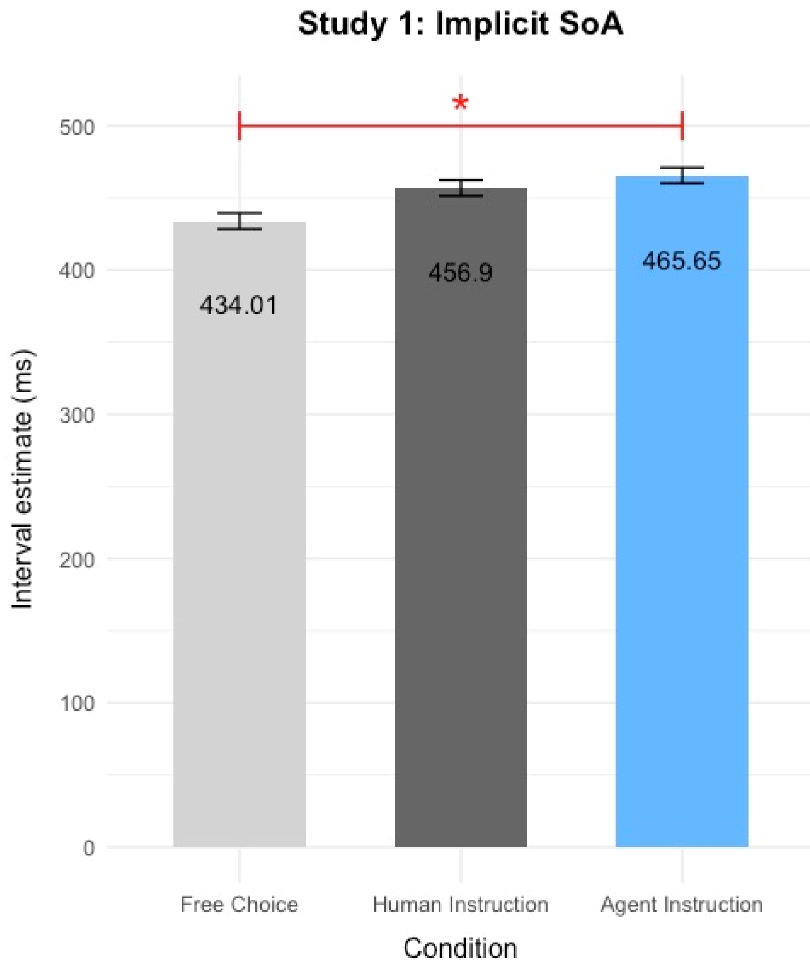

Fig. 2. ***Participants' interval estimates per condition.*** Participant interval estimates are displayed on the y-axis. The x-axis shows each within-subject condition. Mean values are displayed for each condition within their respective bars. Error bars represent SE for each condition. An asterisk (*) indicates statistical significance at $p < .05$.

Pairwise comparisons (Bonferroni corrected) were conducted to examine differences between conditions. The results revealed a statistically significant difference, $t(39) = -2.7$, $p = .03$, $d = -0.29$, 95% CI [-0.57, -0.01], between the Free Choice ($M = 434.01$, $SD = 106.44$) and Agent Instruction conditions ($M = 465.65$, $SD = 107.87$) wherein participants' interval estimates were significantly shorter in the Free Choice condition when participants could freely choose between pressing the left or right key at their own pace compared to when keypress were instructed by an on-screen chatbot (see Fig. 2). However, there were no statistically significant differences in interval estimates between the Free Choice and Human Instruction ($M = 456.90$, $SD = 111.48$) conditions, $t(39) = -1.95$, $p = .17$, $d = -0.21$, 95% CI [-0.49, 0.07]. Additionally, the difference between the Agent Instruction and Human Instruction conditions were not found to be statistically significant, $d(39) = -0.8$, $p = 1$, $d = -0.08$, 95% CI [-0.33, 0.17]. These results indicate that the difference in participants' interval estimates was not significant when instruction was delivered by a human compared to a free choice condition, where participants conducted keypresses of their own volition. Additionally, the difference between instruction agent (human vs. artificial) was not found to be statistically significant.

To further explore our data, we conducted a post hoc exploratory analysis to examine the potential presence of a linear trend using the statistical software JASP (version 0.19.3; JASP Team, 2025). The results were statistically significant, $t(39) = 2.69$, $p = .01$, d = 0.21, 95% CI [0.04, 0.37], indicating that interval estimates demonstrated an increase across each condition, wherein participants' interval estimates were lowest in the Free Choice condition, increased in the Human Instruction condition, and were the largest in the Agent Instruction condition.

3.2.3 Discussion

Study 1 examined how action instructions from a human and an on-screen chatbot influenced SoA. In this study, we used the implicit method of IB as our measure of SoA wherein participants estimated the time interval between when they pressed a key and when they heard a tone that was delayed by 100, 400, or 700 ms. We used a within-subjects study design involving three conditions: in the Agent Instruction condition, keypresses were prompted by an on-screen chatbot; in the Human Instruction condition, instructions were given by a human experimenter present in the room; and in the Free Choice condition, participants performed keypresses voluntarily and at their own pace. The results revealed a statistically significant difference between the Free Choice and Agent Instruction conditions. No statistically significant differences were observed between the Free Choice and Human Instruction conditions or between the Human Instruction and Agent Instruction conditions. Additionally, we identified a statistically significant linear trend wherein participants' interval estimates were the lowest in the Free Choice condition, increased in the Human Instruction condition, and increased further in the Agent Instruction condition.

To address the limitations of IB as a measure of SoA, we conducted a follow-up study using a similar protocol to gain a more nuanced understanding of how action instructions from a human versus an artificial agent influence SoA. In Study 2, we employed similar study methods to those used in Study 1; however, instead of using IB as an implicit measure of SoA, we incorporated the explicit measure of self-reported control ratings.

3.3 Study 2: Action instruction effects on explicit SoA

3.3.1 Methods

3.3.1.1 Participants

In keeping with Study 1, we recruited the same number of participants resulting in a sample size of 40 participants (30 female, $M_{\text{age}} = 19.05$, $SD_{\text{age}} = 2.61$). Participants consisted of first-year psychology students recruited from McMaster University's undergraduate student pool. Normal or corrected to normal vision and hearing was required for participation in this study. Thirty-five participants reported being right-handed (88%) and remuneration was provided in the form of course credits (0.5 credits per 30 mins) for engaging in the study. The study was approved by the McMaster University Ethics Board and conducted in accordance with ethical guidelines of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.

3.3.1.2 Study materials and design

This study followed the same design and incorporated similar materials as Study 1, consisting of a within-subjects design with three conditions as the experimental factor (Free Choice, Agent Instruction, Human Instruction). The order of study conditions was counterbalanced using the Latin Squares method (Grant, 1948). The experiment was programmed using PsychoPy (version 2024.1.5; Pierce et al., 2019) and conducted on a Lenovo ThinkCentre M910z Signature Edition desktop computer (Intel Core i7-7700 CPU @ 3.60 GHz, 64-bit) running Windows 10 Pro (version 2009, OS build 19045.4412). A 20-inch Lenovo desktop monitor (model LEN-M910z-B) was used to display the experiment, with a screen resolution of 1920 × 1080 pixels and a refresh rate of 60 Hz. Screen brightness was maintained at the maximum setting throughout the experiment, and audio volume was standardized at 70 decibels for all participants. Participants used a wired Dell computer mouse (model MO56UOA) to navigate the task and a Lenovo keyboard (model KU-0225) to enter responses.

As the explicit measure of agency, we employed a similar task to that of Study 1 however, instead of estimating the time interval between an action and its outcome, participants were asked to self-report their perceived level of control over pressing a key on a keyboard and hearing a tone. Two keys served as the designated 'action' keys: the left key (z), labeled with a round sticker marked 'L', and the right key (m), labeled with a round sticker marked 'R'. After pressing a key, a tone would play after a random delay of either 100, 400, or 700 ms. Each delay occurred 16 times over 48 experimental trials and in random order. Once the tone was played, participants were shown an on-screen sliding scale and asked to respond to the question "How much do you feel like you caused the tone to play?" (Imaizumi & Tanno, 2019). The control rating was conducted on a sliding Likert-style scale. The scale ranged from 1 to 9, with increasing values at each point, and was anchored at 1 ('Not at all'), 5 ('Somewhat') and 9 ('Very much'). The slider consisted of a small circular marker and initially appeared in the middle of the scale corresponding to a value of 5.

We used the same on-screen chatbot to provide keypress instructions for the Agent Instruction condition as was used in Study 1. The chatbot, referred to as Cogito, had the same visual appearance and used the same audio output to provide action instructions ("Press the left/right key"). For a more detailed description of Cogito, see Section 2.1.2. Study materials and design.

3.3.1.3 Procedure

Eligible participants were individually invited to attend the in-lab study. In the lab, participants received information about the study. Consent to participate was provided by having participants digitally respond to an online form. Following this, verbal instructions about the study were provided by the experimenter. As in Study 1, the order of conditions was determined using the Latin Squares method. Each condition began with six practice trials followed by 48 experimental trials.

In keeping with Study 1, each condition followed the same procedure with the exception of the IE task, which was replaced by the self-reported control rating (see Fi. 3). In the Free Choice condition, participants could choose to press either the left or right key freely and at their own pace to progress through each trial. At the start of this condition, participants were provided with a prompt that read, "In this part of the study, YOU will have the option to decide for yourself and choose which key to press." Participants began the study trials by clicking a 'continue' button located at the bottom of the screen using the computer mouse. Each trial began with a fixation cross centered on the screen and the following text appearing above: "Press either the LEFT or RIGHT key to hear a sound." After making each keypress, participants heard a tone after a random delay of either 100, 400, or 700 ms. Participants then used the computer mouse to indicate their perceived level of control over causing the tone by dragging a slider on a sliding scale. After making their response, a 'continue' button appeared at the bottom of the screen. Once clicked, the trials repeated.

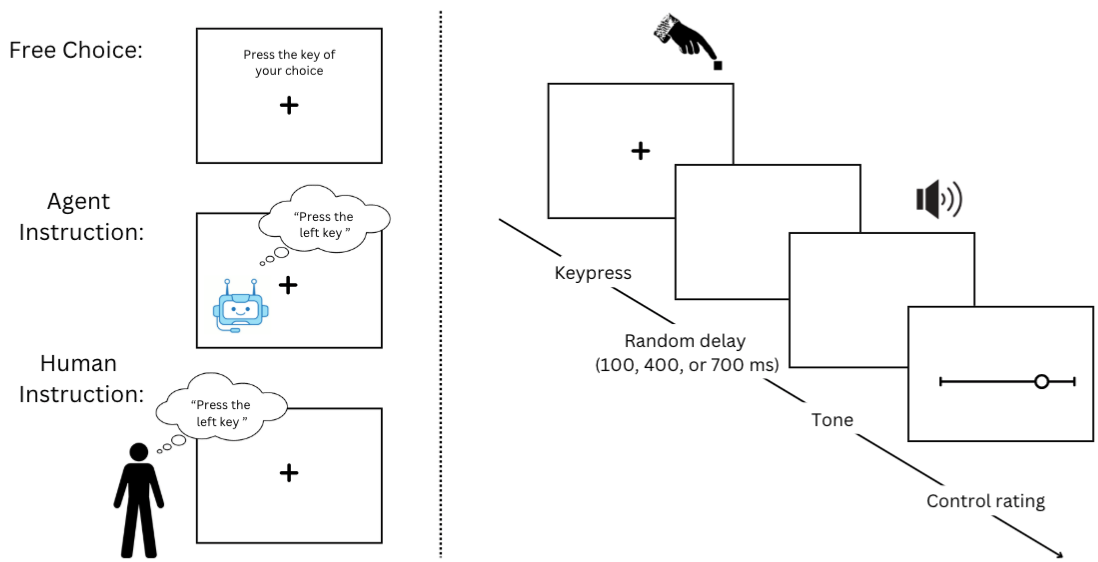

Fig. 3. ***Depiction of the control rating task and experimental conditions.*** *The right panel indicates how each trial starts depending on the experimental condition. In the Free Choice condition, participants are shown a fixation cross and are free to press the key of their choice to trigger a tone. In the Agent Instruction condition, an on-screen chatbot appears beside a fixation cross and instructs the participant to press either the left or right key. In the Human Instruction condition, the experimenter in the room instructs the participant which key to press (left or right). After the keypress, a tone is played following a random delay of 100, 400, or 700 ms. Participants then report how much control they felt over causing the tone.*

In the Agent Instruction condition, participants received verbal keypress instructions ("Press the left/right key") from the on-screen chatbot Cogito before completing the control rating. The condition began with on-screen instructions that read, "In this part of the study, an AI CHATBOT will instruct you which key to press. It is important that you do not press any key before the AI chatbot instructs you which key to press." Each trial began with a fixation cross in the center of the screen. Cogito appeared to the left side of the screen and provided verbal instructions by saying "Press the left/right key." Cogito and the fixation cross disappeared at the keypress and a tone was played after a random delay (100, 400, or 700 ms). Participants then indicated their perceived level of control using the sliding scale. Once a response was completed, a 'continue' button appeared at the bottom of the screen. The trial repeated once participants clicked this button using the computer mouse.

In the Human Instruction condition, keypress instructions were provided by the female experimenter in the room. The experimenter sat in a chair to the right of participants. The on-screen instructions for this condition read, "In this part of the study, the EXPERIMENTER will instruct you which key to press. It is important that you do not press any key before the experimenter instructs you which key to press." Each trial began with a fixation cross in the center of the screen. The experimenter would then instruct participants to "Press the left/right key." Keypress instructions were evenly distributed, with participants instructed to press the left key 24 times and the right key 24 times in a random order. After pressing a key and hearing a tone (randomly delayed by 100, 400, or 700 ms), participants reported their control rating using the mouse to select a value on the sliding scale. After making their selection, a button labeled 'continue' appeared on the bottom of the screen. The trial repeated after participants used the mouse to select the button.

At the conclusion of the study, participants provided demographic information using an online survey hosted by the platform LimeSurvey (LimeSurvey GmbH, n.d.). Participants were then debriefed, remunerated, and thanked for their times. Each study session took approximately 30 minutes to complete.

3.3.2 Results

3.3.2.1 Data analysis

Data processing, visualization, and analyses were conducted using R v.4.4.2 (R Core Team, 2024) with R pack ages dplyr (Wickham et al., 2023), tidyverse (Wickham et al., 2019), psych (Revelle, 2024), car (Fox & Weisberg, 2019), rstatix (Kassambara, 2023), and ggplot2 (Wickham, 2016). Normality testing was conducted using the Shapiro-Wilk test and equal variances were determined via the Bartlett test of homogeneity. Data was determined to be unequally distributed and therefore a squared (quadratic) transformation was applied to the data prior to analysis. After transforming the data, we conducted a rmANOVA to examine the effect of condition (Free Choice, Agent Instruction, Human Instruction) on participants' control ratings. Greenhouse-Geisser corrections were applied to adjust for violations of sphericity. The results revealed a statistically significant effect of condition, $F(1.52, 59.13) = 16.42$, $p < .001$, $\eta^2 = 0.156$, on participants' self-reported control ratings.

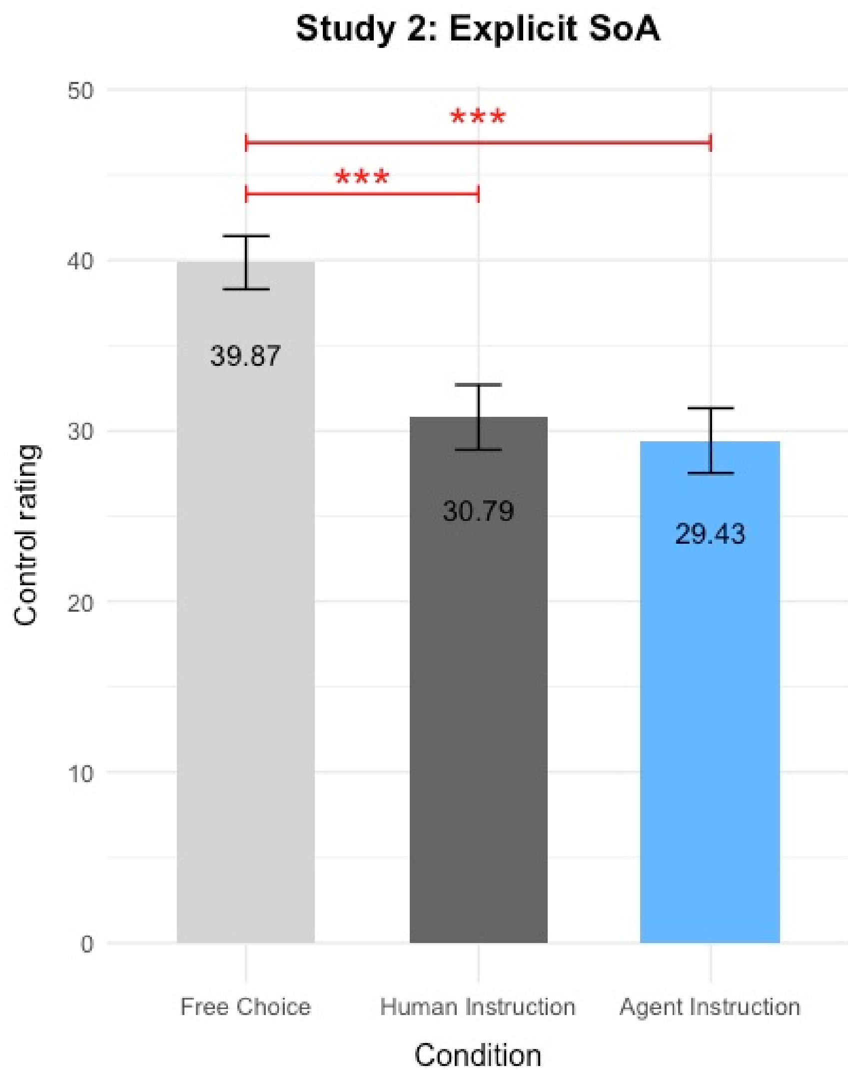

Fig.4. ***Participants' self-reported control ratings per condition.*** Participant control ratings are displayed on the y-axis. The x-axis shows each within-subject condition. Mean values are displayed for each condition in corresponding bars. Error bars represent SE. Asterisks (***) indicate statistical significance at $p < .001$.

Post hoc pairwise comparisons (Bonferroni corrected) indicated a statistically significant difference between the Free Choice (M = 39.87, SD = 9.87) and Agent Instruction (M = 29.43, SD = 12) conditions, $t(39) = 4.6$, $p < .001$, $d = 0.92$, 95% CI [0.36, 1.49], wherein participants who were instructed which key to press by the on-screen chatbot had significantly lower control ratings compared to in the Free Choice condition where keypresses were conducted of their own volition. Additionally, a statistically significance difference was revealed for the Free Choice and Human Instruction (M = 30.79, SD = 12.1) conditions, $t(39) = 4.1$, $p < .001$, $d = 0.8$, 95% CI [0.26, 1.34], wherein control ratings were significantly lower when participants received instructions from a human experimenter compared to when they were free to choose which key to press. However, participants' control ratings did not differ significantly between the Agent Instruction and Human Instruction conditions, $t(39)$

= 1.05, p = .91, d = 0.12, 95% CI [-0.17, 0.41], suggesting that the type of agent delivering action instructions (human vs. artificial) did not significantly influence perceived control. Data are visualized in Figure 4.

Finally, we conducted a post hoc analysis to explore the presence of a linear trend using the statistical software JASP (version 0.19.3; JASP Team, 2025). The results were statistically significant, t(39) = -4.58, p < .001, d = -0.65, 95% CI [-0.97, -0.33], indicating that participants' control ratings were the greatest in the Free Choice condition, decreased in the Human Instruction condition, and decreased further in the Agent Instruction condition.

3.3.3 Discussion

Study 2 explored how action instructions from a human and an artificial agent influence SoA. In this study, we used an explicit method as our measure of SoA wherein participants self-reported their feelings of control over pressing a key on a keyboard and hearing a tone after a random delay of either 100, 400, or 700 ms. Similar to Study 1, participants engaged in three conditions: (1) Free Choice, in which participants were able to freely choose between pressing a left or right key on a keyboard; (2) Agent Instruction, in which participants were instructed which key to press by an on-screen chatbot; and (3) Human Instruction, in which the experimenter in the room provided keypress instructions.

The results revealed a statistically significant difference between the Free Choice and Human Instruction conditions and between the Free Choice and Agent Instruction conditions. However, there were no statistically significant differences between the action instruction conditions (Human Instruction and Agent Instruction). Additionally, post hoc analyses revealed the existence of a statistically significant linear trend, wherein overall, participants control ratings were the highest in the free choice condition, decreased when under human instruction, and decreased the furthest when action instructions were directed by an on-screen chatbot. The results, taken together with those from Study 1, are further examined in the General Discussion section below.

3.4 General Discussion

As technology continues to evolve, there is a critical need to better understand how the human experience of agency is influenced when instructions to act come from non-human sources. Over two studies we administered similar protocols to explore the relationship between the agent type delivering action instructions and SoA using implicit and explicit measures. In Study 1, we addressed this question via IB, a widely used implicit measure of agency. Each participant engaged in three conditions where they could choose to make a keypress of their own volition (Free Choice condition) or they were instructed which key to press by either a human experimenter (Human Instruction) or an on-screen chatbot (Agent Instruction). After each keypress, participants heard a tone that was randomly delayed by either 100, 400, or 700 ms. Participants were then asked to estimate the temporal interval between each action (keypress) and its corresponding effect (tone). The results of Study 1 indicated that, overall, binding was the greatest in the free choice condition wherein participants' actions were conducted under their own volition and without external instruction. This result is consistent with previous studies that have shown the strongest binding for freely chosen actions (e.g., Barlas & Obhi, 2013; Barlas, 2019). As expected, numerically, participants' interval estimates decreased for both the Agent and Human Instruction conditions. Additionally, we observed a statistically significant difference between the Agent Instruction and Free Choice condition, which aligned with our initial hypothesis. In an additional exploratory analysis, we observed a significant linear trend whereby interval estimates were the shortest in the Free Choice condition, increased in the Human Instruction condition, and increased further in the Agent Instruction condition. This finding suggests that external instruction systematically influenced participants' interval estimates, with instruction from the artificial agent corresponding to progressively longer perceived intervals.

In Study 2, we administered a very similar procedure that implemented the same conditions as used in Study 1; however, we used an explicit self-report measure to quantify SoA. The results of this study were similar in that participants' self-reported feelings of control were the greatest in the Free Choice condition. In contrast with Study 1, we observed significant differences for both instruction conditions (Human and Agent Instruction) when comparing control ratings to the Free Choice condition. The results of this study showed that participants' self-reported feelings of control were generally lower when under human and agent instruction compared to when actions are freely conducted. This finding contrasts somewhat with Study 1, where significant differences were observed only between the Agent Instruction and Free Choice conditions. Additionally, we observed a similar statistically significant trend wherein participants' control ratings were the greatest in the Free Choice condition, decreased when actions were conducted under human instruction, and decreased the furthest when under agent instruction. Across both studies, no statistically significant differences were found between the two instruction conditions (Human Instruction vs. Agent Instruction).

Generally, differential findings for studies employing implicit vs. explicit measures of SoA can be attributed to distinctions between these measures in how they capture the experience of agency. At the implicit level, agency can be understood as a pre-reflective state (Synofzik et al., 2008, Gallagher, 2000), given that it does not involve conscious processes. Therefore, this facet of agency is thought to arise from the interaction of motor commands and sensory input, reflecting underlying sensorimotor processes (Moore et al., 2012). On the contrary, explicit dimensions involve higher-order conceptual judgements, wherein an individual must make conscious attributions of agency. This represents a reflective state, where judgements regarding one's agency are typically made after observation of action effects. As such, the findings pertaining to implicit and explicit SoA may be conceptualized as complementary components of a unified construct.

In the context of prior literature on the effects of free choice vs instructed action on SoA, the absence of a significant difference between human-instructed and freely chosen actions in Study 1 was not unexpected, given the mixed findings on the effect of action instruction on binding. Additionally, there is precedent in the literature for the lack of such an effect for low numbers of action alternatives. For example, in the original study that investigated the effects of free choice vs instructed action on IB, Barlas & Obhi (2013) found significantly greater IB in the free choice condition in which there were seven action alternatives (i.e., seven possible buttons to select from) compared to the instructed condition. However, these authors did not find a significant difference in binding between the free choice condition involving three action alternatives and the instructed condition. Despite this pattern, a subsequent experiment by Barlas (2019) did show differences between a free choice condition and an instructed condition when only two action alternatives were available. In the current experiment, it is unclear whether a statistically significant difference in interval estimates would have emerged between the Agent and Human Instruction conditions, or between the Free Choice and Human Instruction conditions if there were more action alternatives (keys on the keyboard) to choose from. That said, the linear trend we observed does suggest that human-instructed and agent-instructed action contexts are characterized by differing experiences of the temporal relationship between actions and effects and, by extension, differing levels of agency.

One interesting question arising from the comparison between the study of Barlas (2019) and our study is that we employed an on-screen chatbot to provide action instructions whereas the previous study employed a physical robot. The extent to which a physical robot and a chatbot, both considered artificial agents, are perceived as similar when delivering action instruction is an open question that requires further investigation (note that some previous work has used physical robots and specifically described them as “AI robots”—see Dang & Liu, 2021, for example). Additional work is needed to better understand how the physical form of an artificial agent mediates SoA under action instruction. Additional factors, such as perceived trust, anthropomorphism, and individual differences (e.g., familiarity with technology and consistency of its use) may also serve as mediators in these interactions (Oksanen et al., 2020, Blut et al., 2021).

There are some limitations to this study that require consideration. Firstly, given that our participants were recruited from individuals enrolled in a first-year university psychology program, our study sample contains relatively young adults and is heavily female-biased. It is possible that young female participants might respond differently to action instructions and therefore, caution should be taken when generalizing the results of these findings (Eagly & Carli, 1981). Notably, instructions for the human condition of this experiment were delivered by a female experimenter and as such, the voice of the on-screen chatbot Cogito was customized to have a feminine tone. Therefore, it remains unclear how instructions delivered by a male experimenter or a masculine-sounding chatbot might influence the results, especially given evidence that responses to instruction can vary based on factors such as gender stereotypes (Carli, 1990; Eyssel & Hegel, 2012). Furthermore, participants in this study were given only two key choices in all conditions. Although restrictions on action choice were imposed through the instruction conditions, participant actions were also somewhat constrained in the free choice condition. Given that participants could only choose between two keys (left or right), participants were relatively limited in choice despite this choice being of their own volition. Future studies might consider eliminating this key restriction and allowing participants in a free choice condition the opportunity to press any key to advance each trial. Finally, the on-screen chatbot's delivery of instructions could be considered as being more rigid compared to that of the human experimenter, potentially having an influence on SoA. For instance, the timing of the human experimenter's keypress instructions varied naturally at the start of each trial, introducing a degree of spontaneity that was absent in the artificial agent condition, wherein the chatbot was programmed to deliver the instruction at 1650 ms from the start of each trial. When an instruction occurs at a set interval each time, such as in the Agent instruction condition, it might further reduce an individual's experience of control, given that they are constrained by this fixed schedule (Yu, 2019). Instruction that is randomly timed, such as in the human instruction condition, allows for greater unpredictability, potentially mitigating an agency reduction if the participant isn't tied to a rigid pattern.

In sum, the results of this study indicate that action instruction from humans and artificial agents can have significant implications for the SoA. Specifically, receiving instructions from an on-screen chatbot to conduct an action significantly reduces implicit SoA (indexed by longer action-effect interval estimates) compared to action that is conducted without external instruction (under one's own volition). Additionally, instruction, regardless of the instructing agent, reduces perceived levels of control (explicit SoA). Reductions in SoA can have several implications for the outcomes of actions in daily life and society. For example, individuals experiencing a diminished SoA are less likely to perceive themselves as being responsible for the outcomes of their actions (Bandura, 1999; Haggard, 2017). As artificial agents continue to adopt roles involving instruction delivery, understanding the influence of instruction from artificial agents on SoA is necessary for understanding the broader impact of human interaction with technology.

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Chapter 4

General discussion

4.1 The social construction of agency

This thesis explored the influence of social moderators, including acute psychosocial stress and the source of action instruction, on the SoA. Through a multifaceted approach, we aimed to deepen our understanding of how common, everyday experiences, such as experiencing stress or receiving instructions to perform an action, shape an individual's perceived sense of control over their actions and the resulting outcomes.

In both empirical chapters of this thesis (Chapters 2 and 3), we employed a combination of implicit and explicit measures of agency to offer a more nuanced understanding of experiences related to agency. In Chapter 2, we used a pre- post-test design to understand how the influence of psychosocial stress affects SoA across two studies. Each study used the same methodology, however; Study 1 employed an explicit measure of self-report to obtain measures of agency and Study 2 used the implicit measure of IB to quantify agency. After obtaining a baseline measure of agency and stress, participants underwent either a stressful condition, induced by the TSST , or a neutral condition, which employed a placebo version of the TSST (Kirschbaum et al., 1993). Post-test measures of stress and agency were then obtained and compared to its baseline. The results of Study 1 (explicit) showed that participants who underwent the stressful condition reported higher levels of SoA for outcomes following a 700 ms delay compared to those in the control condition. However, this effect was modest and did not remain significant after correcting for multiple comparisons. In Study 2 (implicit), participants in the stress condition exhibited significantly shorter temporal estimates than those in the control condition, specifically at the 700 ms delay. This finding was robust, suggesting that psychosocial stress may enhance SoA for delayed outcomes. We refer to this phenomenon as being a potential "stress-enabled agency boost," which may be linked to the activation of the fight-or-flight response (Edwards et al., 2025).

Chapter 3 followed a similar approach to understanding agency in the context of action instruction—as in the previous chapter, we explored the effects of action instruction on both implicit and explicit SoA across two studies. Using a within-subjects design, we examined how the source of action instruction, whether instruction was delivered by a human or an on-screen chatbot, affects the SoA. In Study 1, IB was strongest in the free choice condition wherein participants acted of their own volition and was significantly reduced when actions were instructed by a chatbot. In Study 2, participants' perceived levels of control were the highest in the free choice condition and significantly lower in both human- and agent-instructed conditions. Notably, both studies within this chapter revealed a consistent linear trend, with human-instructed actions falling between free choice and agent-instructed actions in terms of both temporal binding and perceived control. These findings offer valuable insights into how individuals experience agency in response to human- versus technology-driven instruction.

4.2 Chapter 2: Under stress and in control? Investigating psychosocial stress and the sense of agency

In Chapter 2, we attempted to further explore the limited literature on the effects of stress on SoA. Previous work has shown no effect of embodied stress on agency (Stern et al., 2020) and a negative effect of stress on SoA (Chu et al., 2023). We employed a very similar procedure to that of Chu and colleagues (2023), which used a pre- post-test design. Our findings indicated that stress has a positive effect on participants' SoA but only for action outcomes that occur after a 700 ms delay. These findings were not aligned with the previous work on agency and stress however, direct comparisons are difficult given that previous work did not explore temporal delay as a factor.

Important limitations regarding this work include sample size, specifically for Study 1 within this chapter. Given that our sample size was based on previous studies, collecting a larger participant pool might provide a more in-depth understanding of the relationship of stress on explicit SoA that was not appropriately captured by the limited power in our study. Additionally, our sample size was limited in diversity, given that it largely consisted of female undergraduate students from a psychology program. Expanding data collection to include more individuals from the general population would greatly increase the generalizability of future findings related to stress and agency.

Given the preliminary nature of this finding, we encourage future researchers to further explore this topic with an emphasis on temporal delay as a factor. Future work might consider employing similar delays as those used in our study (100, 400, and 700 ms) while including delays larger than 700 ms to determine if such a "stress-enabled agency boost" has a threshold of activation.

4.3 Chapter 3: They told me to do it! How action instruction affects perceptions of control

In Chapter 3, we advanced previous work exploring the effects of action instruction on SoA and focused namely on the agent delivering instructions. While there is much previous literature that has explored the effects of action instruction on agency in general, few studies have provided a direct comparison on the *source* of instruction. Some work has contrasted human- and robot-directed instruction, finding no significant difference between these conditions (Barlas, 2019). Our work in this chapter was the first to extend this line of research with a focus on instruction delivered by artificial agents, namely on-screen chatbots. Across two studies we employed implicit (Study 1) and explicit (Study 2) measures of SoA. It was consistently found that SoA was the highest in a free choice condition and decreased when actions were instructed. Notably, we only observed a statistically significant difference between the free choice and agent-instruction conditions of Study 1. In Study 2, self-reported ratings of control were significant when comparing both instruction conditions (agent and human) with free choice. A significant linear trend was observed across both studies wherein agency was the greatest numerically in the free choice condition, decreased for the human-instruction condition, and decreased the furthest for the agent-instruction condition.

Given that the instruction in this study is relatively elementary, wherein participants are asked to press either a left or right key on a keyboard, future work might consider increasing the complexity of instructions. Additionally, it would be of interest to examine whether the valence of outcomes following agent versus human instruction (i.e., negative, neutral, or positive) modulates an individual's experience of agency in these contexts, given that some previous work has shown that perceptions of agency when under human-directed instruction can vary depending on the nature of action outcomes (see Caspar et al., 2018; 2021).

4.4 Final conclusions

This thesis explored the complex integration of social moderators on SoA—the experience of control over one's actions and their outcomes. We found that psychosocial stress may enhance feelings of agency for outcomes that occur after a 700 ms delay, a result that contrasts previous findings showing null or negative effects of stress on SoA (Stern et al., 2020; Chu et al., 2023). We concluded that this finding may reflect a "stress-enabled agency boost" for increasingly delayed action outcomes. This study was the first to consider time delay as a moderating factor in the effects of stress on SoA and as such, more work is needed to better elucidate these preliminary findings.

Additionally, we found that agency decreases when actions are instructed by either a human or a chatbot, compared to actions that are freely chosen. This finding was in line with previous research, which overall indicates that instructed action from humans and robots will often decrease the SoA (Barlas et al., 2018; Barlas, 2019; Huang et al., 2024; Zanatto et al., 2023a; Casper et al., 2016; Akyüz et al. 2024). This study was the first to employ online artificial agents, in the form of on-screen chatbots, as an instructing agent, providing new insights into how humans interact with technology and its effects on perceptions of agency.

The work presented in this thesis provides early steps towards a greater understanding of the nuanced relationship between social factors and the experience of agency. Here, we show how stress and instruction, two common features of everyday life, can meaningfully shape how individuals perceive control over their actions and outcomes. Taken together, these findings add to the rapidly growing body of literature on agency and provide insight on how specific interactions with both humans and technology can shape perceptions of control. As social interactions with technology continue to increase, understanding how such interactions shape perceptions such as the SoA will be crucial for navigating an increasingly mediated social world.

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