The effect of effort and individual differences on the implicit sense of agency.

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Abstract

The experience of feeling responsible for the outcomes of one's actions is known as the *sense of agency*. The phenomenon of reduced perceived temporal proximity between actions and their effects is thought to implicitly index the sense of agency, and is known as temporal or intentional binding. The optimal cue integration account indicates that the sense of agency is dependent of the integration of several cues. This thesis uses temporal binding to investigate instances which afford cues that may hinder the generation of agency. Chapters 3 and 4 examine the modulatory roles of physical and mental effort finding that the implicit sense of agency reduced under physical and mental strain. In Chapter 5, electroencephalography was used to investigate the influence of mental effort on neural response to action outcomes. Concordant with previous findings, neural responses to self-generated outcomes were reduced (i.e. attenuated readiness potentials and N1 components), however, the effect of effort was less reliable, providing limited evidence for the role of individual task difficulty on the attenuation of the readiness potential. Chapter 6 found that high levels of (subclinical) schizotypy weakened the sense of agency, whereby temporal binding was less distinguished across conditions of agency and no agency. In Chapter 7, it was shown that the affective content of social stimuli did not modulate temporal binding, nor did individual differences in social anxiety. Overall, these findings support the notion that the sense of agency is dependent on the availability of cognitive resources, and in contexts in which agency cues concurrently deplete these resources, either by physical or mental effort, or in individuals with tendencies to attribute agency inappropriately, agency is weakened. Nevertheless, the lack of modulation by emotional stimuli and by anxiety provide informative boundary conditions for these effects. Beyond contributing to our understanding of this key aspect of human experience, work in this area could influence how society considers responsibility in everyday life and in law, and how aberrant experiences of agency can be understood in disease.

Contents

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The candidate has not previously submitted any of this work towards the award of a degree.

Some of the research presented in this thesis has been communicated to the scientific community. Experiments 1, 2, 4 and somewhat Experiment 3 have been presented in a paper (Howard, Edwards & Bayliss, 2016; see Appendix 1).

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Chapter 1: Introduction

It is important that humans can efficiently process events which are the result of its own actions, and to discriminate these from events in the world for which it is not responsible. For instance, if I press the horn button on my car and then hear may car ‘honk’, I know my action of pressing the horn button was responsible for the beeping sound. Self-authored events like this tend to be easy to identify and are accompanied by a conscious experience of control over the ability to cause change in the external world known as the *sense of agency*.

There are however, instances in which the sense of agency is not correctly ascribed. Aberrant experiences of agency are most noticeable in disorders with symptoms characteristic of abnormalities in self-reference. This is due to their stark peculiarities and deviance from normal behaviour. For instance, in schizophrenia auditory hallucinations are experienced because the inner voice is misinterpreted as having an external agent, and in alien hand syndrome the sufferer experiences a loss of volition and control in the affected limb. However, disruptions of agency ascription are not confined to disorders, rather they are also apparent in the healthy population and can occur so frequently that they are considered a normal perception. For instance, the sense of agency can be experienced for an action that was not carried out by the self. Imagine for instance the pride and feeling of accomplishment of a member of a winning football team, even when this member sat on the bench the entire match. Agency can also be rejected for self-generated actions when acting under coercion, with responsibility being denied because “*they made me do it*”. Moreover, the act of cyberbullying may function as result of online anonymity and the absence of observing the distressing effects in the victim weakening the sense of agency over the abuse. Agency is also intimately linked with responsibility, both of which can be rejected when outcomes, particularly when negative, are the result of an action for which the agent had no control. For instance, whilst distracted by nuisance children on the back seat the sense of responsibility over crashing into the bumper of the car in front may be reduced, and actions committed under intoxication can also be accompanied with a reduced sense of agency.

The sense of agency is generated through the culmination of many internal and external cues. Previous research into the sense of agency generally aims to reveal the cues which *aid* the construction of the sense of agency. It is also important, however, to understand contexts in which cues *hinder* the construction of agency, in addition to contexts in which cues have *no effect* on the construction of agency. To do this the generation of agency can be placed within contexts that afford cues encountered in everyday life. For instance, everyday behaviour can require varying degrees of exertion, both physical and mental, such as when we are carrying heavy shopping bags or experiencing varying levels of cognitive strain, such as fatigue, stress, or multitasking. Humans are also social beings with our actions having direct social consequences. For instance, not only do humans perform actions in social settings, but these actions may also have social emotional consequences. Moreover, the perception of agency and responsibility may also be influenced by our personalities. These important contextual cues, however, haven't received much empirical interest in the field of the sense of agency.

This thesis therefore aims to examine the generation of agency in circumstances with these varying cues. In particular, this thesis examines the role of physical and mental effort, the influence of levels of schizotypy and social anxiety, and the role of social valence and gaze orientation on the sense of agency. The aim of the thesis is to obtain further insight as to the contexts in which agency cues can hinder the implicit measure of agency, and boundary conditions in which the sense of agency is robust. The investigation into contexts which can modulate the sense of agency, and those which cannot, have value in informing how culpability and responsibility is understood. This has further important implications for how the justice system deals with criminal acts under certain conditions.

The attribution of agency

The sense of agency is generated in a process that is undertaken automatically and with ease in everyday life, providing rapid and information-rich judgements concerning one's influence on the world. The scientific interest into this subject area has grown considerably since the first investigations into voluntary action and sense of agency (David, Obhi & Moore, 2015; Haggard, Clark & Kalogeras, 2002). In this Chapter I address some existing contributions to the understanding of the sense of agency, distinguishing between judgements and feelings of agency and how they are believed to emerge. Furthermore, I discuss methods in which agency can be measured, highlighting the role of time perception as an implicit measure of the sense of agency and how it is appropriate for this purpose.

The experience of agency

The sense of agency is the result of the integration between two components, judgements of agency and feelings of agency (Synofzik, Vosgerau & Newen, 2008). Judgements of agency refer to high-level conclusions concerning the authorship of an action or effect, and arise when agency is explicitly made aware of. They are influenced by top-down cognitive processes such as background beliefs and action related knowledge. Feelings of agency, on the other hand, refer to low-level processes generated by sensorimotor signals. Because judgements of agency are not generated from sensorimotor signals, agency can attributed to events when a self-generated action has not caused it. Judgements of agency are therefore more sensitive to causality and contingency between events (Gallagher, 2000). Feelings of agency and judgements of agency are intimately linked with feelings of agency forming a necessary but not sufficient condition for a judgement of self-agency to be made (Haggard & Tsakiris, 2009). Such that, although feelings and judgements of agency tend to occur simultaneously, they can also be dissociated. For instance, judgements of agency can be experienced for actions not generated by the self (Wegner, Sparrow & Winerman, 2004).

Models for agency attribution.

There have been competing views regarding how a sense of agency is constructed. On one hand, according to the forwards models of motor control, the sense of agency is believed to manifest as a result of *internal* cues of pre-reflective motor and sensory predictions (Blakemore, Frith & Wolpert, 2001; Blakemore, Wolpert & Frith, 2002). On the other hand, the sense of agency is believed to result from *external* cues from reflective post-hoc inferences regarding the context (Wegner, 2002; Wegner, 2003; Wegner & Wheatley, 1999). Both of these views have been challenged by the optimal cue integration account, in which it is believed that both internal and external cues are thought to contribute to a sense of agency (Moore & Fletcher, 2012; Moore, Wegner & Haggard, 2009; Synofzik, Thier, Leube, Schlotterbeck, & Lindner, 2010; Synofzik, Vosgerau, & Lindner, 2009; Synofzik, Vosgerau, & Voss, 2013). All of these accounts are now introduced for their role in the understanding of agency generation.

The comparator model. The comparator model for the sense of agency is an internal forward model, whereby the attribution of agency manifests through predictions of the state of the motor system (the internal forward model) and sensory processing of action outcomes (the forward dynamic model; Blakemore et al., 2001; Blakemore et al., 2002; Davidson & Wolpert, 2005; Wolpert, 1997; Wolpert & Ghahramani, 2000). Predictions of expected sensory consequences as a result of action are created using efference copies through corollary discharge (Sperry, 1950) and compared with acutal feedback of motor and sensory signals through re-afferent signals. If there is a match, or congruence, between the predicted and actual sensory events then the sensory events are perceived as being genereated by the self, and a sense of agency is experienced. If, however, there is a mismatch, or incongruence between the predicted and actual sensory information, the sensory events are percieved as being externally generated, and a sense of agency does not arise. The comparator model has been fruitful in understanding sensory attenuation and deficits in agency in disease (Blakemore, Frith & Wolpert, 1999; Blakemore, Wolpert & Frith, 1998), topics which will be touched on by the current thesis.

The post-hoc inference account. An alternative model, the post-hoc inference account, provides a post-dictive re-constructionist account of agency attribution (Wegner, 2002; Wegner, 2003; Wegner & Wheatley, 1999). Here, sense of agency self-attribution is dependent upon reflection of the action-effect relationship after the outcome has occurred and is based on three factors: exclusivity, priority and consistency. For instance, when there is no other plausible cause for the effect except for it to be self-generated, when there is an intention for the action to have been executed resulting in prior planning of such an action, and when the perceived effects can be explained by the intended action, sense of agency is then retrospectively introduced into consciousness. In this model motor predictions do not account for the ascription of agency. Indeed, it has been found that explicit judgements of self-agency can arise without internal motoric signals (Wegner et al., 2004). Wegner et al. (2004) had participants observe confederate's arms and hand gestures in a mirror. The confederate's arms were in a position that conformed to a natural position to the participant's body. When presented with verbal instructions to make gestures participants reported sensing authorship over gestures executed by the confederate. This was further confirmed with increased galvanic skin responses to the threat of pain to the confederate's hand. This latter effect reflects the responses to non-self-directed threat observed in the rubber hand illusion. In the rubber hand illusion participants experience authorship over a rubber hand following tactile synchronicity on their own unseen hand and a visible prosthetic hand (Armel & Ramachandran, 2003; Botvinick & Cohen, 1998, Ehrsson, Wiech, Weiskopf, Dolan & Passingham, 2006). These findings provide evidence for a sense of agency without the presence of forward predictions of motor commands.

The optimal cue integration account. The ease at which a sense of agency is attributed to the self is a testimony to the reliability of the perceptual system to determine this. For a reliable attribution of agency, it is therefore likely that a range of sources are examined. The optimal cue integration account (Moore et al., 2009; Moore & Fletcher,

2012) suggests that the sense of agency is accountable to multiple sources and recognises the influence of both predictive and postdictive models for agency. Like the comparator model, predictive cues can be motor prediction commands and sensorimotor predictions, with postdictive cues being sensory feedback and proprioception. Background beliefs and knowledge about the world and unconscious primes can further act as pre- or post-dictive cues, thus encompassing elements of the retrospective inference account (Synofzik et al., 2013). It is proposed that cues are integrated to form a suitable estimate of agency by the summing of each individual sensory cue, and weighting them for their importance and reliability (Vosgerau & Synofzik, 2012). This allows for a flexible approach in the attribution of agency, and may account for the differences in agency across contexts and between health and illness (Moore & Fletcher, 2012). Moore and Haggard (2008) provide evidence for the cue integration account by manipulating the probability of the occurrence of an outcome following action. It was found that when probability of the outcome was high the sense of agency was present even when the action did not produce an outcome. Whereas, when the probability of the outcome to an action was low, implicit agency was only demonstrated when the action was followed by an event. In this instance, it is believed that agency was influenced by prior experience regarding the likelihood of an outcome. The prior experience acted as a reliable enough cue to bias towards an agency judgement even in the absence of an action outcome in high probability conditions, and require an action outcome for the attribution of agency in low probability conditions.

The role of time perception for agency

An interesting phenomena occurring under conditions of agency is the illusory shortening of temporal proximity between actions and their effects, an effect known as temporal or intentional binding (Barlas & Obhi, 2013; Engbert & Wohlschläger, 2007; Engbert, Wohlschläger, Thomas, & Haggard, 2007; Haggard et al., 2002; see Moore & Obhi, 2012, for a review). Temporal binding is believed to reflect a sense of agency as it manifests for actions under conditions which are most characteristic and probable of agency. For instance, intentional and volitional actions produce temporal binding, as do predictable action outcomes and contiguity between the action and effect (Barlas & Obhi, 2013; Engbert et al., 2007; Engbert & Wohlschläger, 2007; Haggard et al., 2002; Tsakiris & Haggard, 2003; Tsakiris, Haggard, Franck, Mainy & Sirigu, 2005). Temporal binding occurs because humans have no sense with which to objectively monitor elapsed time.

The sense of time and perceived durations therefore rely on internal mechanisms to determine temporal duration.

Models of time perception. Models proposing internal mechanisms towards subjective time can be classified into either 'intrinsic' or 'dedicated' models (Wittmann, 2013). Intrinsic models suggest that sensory and cognitive processes act as internal meters for the perception of time. For instance, memory decay over time, and the degree of cognitive and emotional energy spent can be indicative of duration (Eagleman & Pariyadath, 2009; Marchetti, 2009; Staddon, 2005). Dedicated models relate to pacemaker-accumulator mechanisms, whereby an accumulation of 'ticks' of an 'internal clock' count the passing of time. The pace of the 'ticks' varies with the degree of arousal and motor activity (Gibbon, Church & Meck, 1984; Treisman, 1963; Wearden, Pilkington & Carter, 1999). When the pace of neural 'ticks' slows, fewer pacing ticks are accumulated and durations appear shorter. Conversely, durations appear longer if the pace of the 'ticks' quickens. The pace of the internal clock is believed to slow during conditions of agency as a consequence of motor prediction. This results in the shortening of subjective time and temporal binding, a phenomena that is believed to reflect the presence of agency attribution (Wenke & Haggard, 2009).

Measuring the sense of agency

The nature of the explicit experience of agency, the role of sensory prediction cues for the generation of agency, and the temporal binding phenomena under conditions of agency gives rise to the sense of agency being investigated using a variety of methods. Methods to investigate the sense of agency are explicit ratings and temporal binding methods which are further explained here.

Explicit ratings of agency. Due to the sense of agency manifesting as an explicit experience sensing that '*I did something'* some investigations rely on explicit ratings of agency. These measures tend to reflect the explicit judgements of agency rather than feelings of agency. Such paradigms require participants to introspect and give either a binary response identifying the agent, or a rating of the degree of self-agency for a given sensory event. For instance, participants are asked if they, a computer or another agent caused a certain event (Aarts, Custers & Wegner, 2005; Dewey & Carr, 2013), or the degree of control and volition participants had over their actions (Hon, Poh & Soon., 2013; Sato & Yasuda, 2005; Wegner et al., 2004). The nature of explicit responses to the degree of agency make this measure susceptible to social desirability effects, whereby participants act in a manner they perceive would be favourable to the experimenter.

Further confounds may be the exaggeration of ratings on scales to match behavioural expectations, or ratings being matched to meaningful or round numbers when responding using a scale (Hornik, 1981; Tversky & Kahneman, 1974). This highlights that explicit ratings measures may not reflect the actual experience of agency.

Sensory predictions in agency. As introduced, comparisons between motor and sensory predictions and effects act as cues for the generation of agency. When motor and sensory effects match predictions an effect occurs whereby the salience of the stimuli is reduced. For instance, self-tickling results in a less tickly sensation than tickles that are caused by another, self-generated tones are perceived as quieter than tones generated by others, and self-generated speech produces attenuated neuronal responses (Bays, Flanagan & Wolpert, 2006; Blakemore et al., 1999; Blakemore et al., 1998; Blakemore, Wolpert & Frith, 2000; Ford, Roach, Faustman & Mathalon, 2007; Timm, SanMiguel, Saupe & Schröger, 2014; Weiss, Herwig & Schütz-Boasbach, 2011). These effects give rise for a measure of agency, with reduced salience and neural processing providing an index of self-agency. These effects are further discussed in Chapter 2.

Temporal binding measures of agency. The nature that actions and outcomes are perceived as occurring closer together in time has given rise to a range of temporal proximity measures with which to investigate the sense of agency. This compression in perceived temporal duration between actions and events is due to the slowing of the pace of ticks in the internal clock, believed to be caused by motor prediction cues present in agentic action (Wenke & Haggard, 2009). In these measures the perceived duration between events is compared with the actual temporal delay. Typically, in conditions of agency the perceived duration is shorter than the actual delay, or the events are perceived as more temporally bound. It is the degree of temporal binding between events which is measured to indicate the degree of agency. These temporal binding measures are believed to be a valid implicit measure of feelings of agency and methods take the form of ‘interval duration estimates’, ‘The Libet Clock method’, and ‘interval reproduction’, each of which are introduced in detail here.

Interval duration estimates. Explicit estimations regarding the duration of the interval is a type of magnitude estimation whereby subjects are required to convert perceived intervals between two events across conditions of agency and no agency, into conventional units of time. The two events marking onset and offset of the interval are typically actions, such as button presses, and a consequential auditory or visual stimuli (Engbert et al., 2007; Engbert, Wohlschläger, & Haggard, 2008; Moore et al., 2009), although in Cravo, Claessens and Baldo (2009), subjects reported the time between the movement offset of a disc and the movement onset of the next disc. The explicit nature of the task brings about similar disadvantages as to the 'explicit ratings of agency' method. For instance, participants are prone to estimate intervals in meaningful multiples or round numbers (Hornik, 1981). Participant responses may be further biased by an anchor effect whereby short durations can decrease estimations and longer durations can increase estimations (Tversky & Kahneman, 1974). Like for explicit ratings of agency, the reported temporal estimations may not represent intervals actually perceived.

The 'Libet Clock' method. Haggard et al. (2002) first reported the use of time perception as a measure for agency using a method adopted from Libet, Gleason, Wright and Pearl (1983). In this type of experiment two events occur, an action and a consequence, the consequence typically being a tone. Subjects are required to make positional judgements of a rotating clock hand at the point one of these events occurs. Positional judgements of one event, either the action or consequence, are then converted into temporal measurements, which are then compared to the actual temporal positions of the events. The typical trial structure of the Libet clock method is shown in Figure 1.

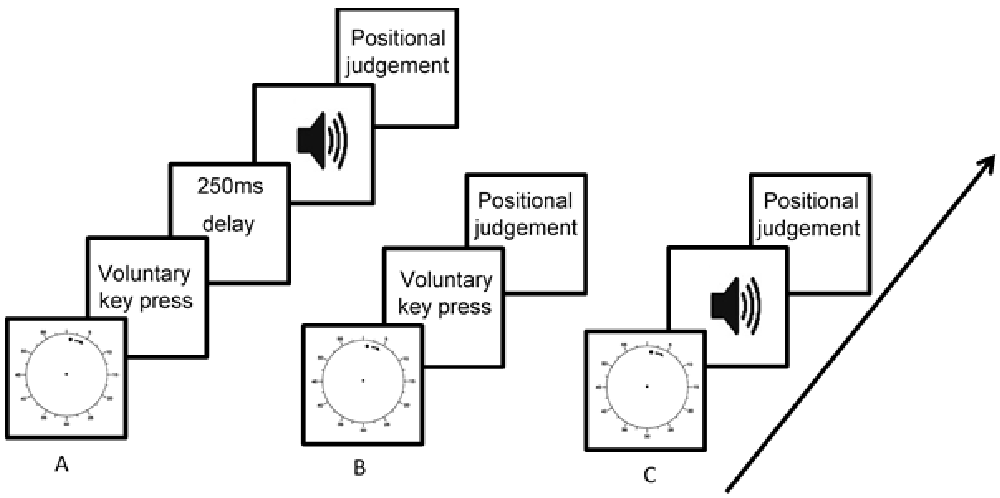

Figure 1. Typical trial procedure for agency conditions (A) and baseline conditions (B & C). In agency conditions subjects made a voluntary key press which produce a tone after a 250 ms delay. Subjects then made positional judgements of either the key press or tone. In baseline conditions subjects either made a key press (B) or heard a tone (C) and then made positional judgements of these events in separate blocks.

The 'Libet Clock' method is the most customary so far with which to investigate the sense of agency (Engbert & Wohlschläger, 2007; Haggard et al., 2002; Moore &

Haggard, 2008; Obhi & Hall, 2011; Strother, House, & Obhi, 2010). This method offers great value in measuring the perceived onset of events rather than interval duration as this allows the investigation into whether it is the action or outcome that is driving the temporal compression. Reporting positional judgments on a clock face also avoids socially desirable responses as the purpose of the task is unknown. However, this method investigates the perceived time of one event rather than the elapsed time between the two events so measures temporal binding indirectly. Also, the nature of dividing attention between the clock and the action may additionally disrupt the processes underlying action control or bias the timing estimate given (Engbert et al., 2007). Again, the reported positional judgements may also not reflect the actual judgements since participants may respond with meaningful or rounded estimates of positional time on the clock face.

Interval reproduction. Buehner and Humphreys (2009) further developed an interval reproduction paradigm which has been adopted and adapted in later research. In a typical interval reproduction paradigm the participant is subject to two events which are separated by a random delay between 500 - 1500ms. In agency conditions the two events are a keypress which is followed by a tone. In no agency conditions the two events are two tones. The participant then reproduces the interval experienced between the two events by the depression of a key for the perceived duration of the interval. Interval reproduction therefore allows for the perceived interval between events to be measured directly, and for experiential reproduction of experienced intervals as opposed to reflective magnitude estimation required by verbal estimates. Thus, there is reduced risk of biased interval estimations since the intervals need not be converted into conventional time units. The use of a passive ‘no agency’ condition also serves as an appropriate comparison condition which accounts for the succession of two events, an important factor considering the intimate link between contiguity, causality and agency (Buehner & Humphreys, 2009). However, in the no agency condition, the onset of the interval between the two events occurs after the first tone yet the participant may perceive the onset of the temporal interval as at the onset of the first tone. In such a case, the interval would be perceived as longer (the actual interval in addition to the duration of the first tone) and may account for some, or all, of the reduced temporal binding effects in no agency conditions compared with agency conditions. This, however, may not be problematic when comparing the effect of another variable across agency and no agency conditions, because if a sense of agency is modulated by variable X its effects should manifest in agency conditions only. This grey boundary of first tone onset can therefore be overcome with appropriate experimental design.

Chapter 1 summary

In this chapter the existing contributions to the construction of the sense of agency has been introduced. I have distinguished between feelings of agency, generated by sensorimotor signals, and judgements of agency, caused by explicit awareness of authorship over actions. Several models have been introduced which explain how the sense of agency arises. For instance, the comparator model indicates that agency is generated when there is congruence between predicted motor and sensory effects, and actual motor and sensory outcomes (Blakemore et al., 2001; Blakemore et al., 2002; Davidson & Wolpert, 2005; Wolpert, 1997; Wolpert & Ghahramani, 2000). On the other hand, the post-hoc inference account suggests that agency is the result of a post-dictive re-constructionist evaluation of the relationship between the action and effect (Wegner, 2002; Wegner, 2003; Wegner & Wheatley, 1999). If there is no other possible explanation except for a stimulus to be self-caused, alongside an experience of the intention to act and knowledge that the untended act results in the stimuli response, then a sense of agency is generated. The third model of agency generation integrates aspects from both the comparator model and the post-hoc inference account, that is the optimal cue integration account. In this model the sense of agency is generated through predictive cues, such as motor and sensory prediction, and postdictive cues, such as beliefs regarding intentions and awareness of the effects a certain act may have. These cues are then weighted for their importance and reliability, and integrated to determine an overall estimation as to the authorship of the action. This third model therefore indicates that the sense of agency is accountable to multiple sources, which explains how the sense of agency can most reliably be generated.

Under conditions of agency, there is an illusory shorting of the length of time perceived between the action and its effect known as temporal binding. This temporal binding effect is believed to reflect the generation of self-agency (Wenke & Haggard, 2009). Chapter 1 introduces how this phenomenon may function as a result of the slowing of the pace of ticks in the internal clock pace-maker (Gibbon et al., 1984; Treisman, 1963; Wearden et al., 1999). Because of the nature that conditions of agency cause temporal binding, several different temporal binding measures are used to capture contexts that give rise to the sense of agency. For instance, interval duration estimates in which participants explicitly indicate the length of an interval; the Libet Clock method in which participants make positional judgements on a clock face for the onset of an action or action-effect; and the interval reproduction method, in which participants reproduce the delay they experienced between an action and the action-effect.

The thesis uses the interval reproduction method to investigate several different circumstances that afford cues for the generation of agency. Because of the nature of the measure of agency, feelings of agency in particular are examined. Navigating our way through day-to-day life presents us with varying contexts in which agency is experienced. This thesis investigates some of these contexts that may offer cues to self-agency, identifying that some contextual cues may hinder or be irrelevant to the generation of agency when agency. These contexts are introduced in the following chapter.

Chapter 2: Literature review

As previously introduced, the optimal cue integration account identifies the role of many contextual cues that can be integrated to account for the sense of agency. The focus of this thesis is therefore to examine the extent to which certain cues afford agency. In particular, this thesis focuses on the role of physical and mental effort, levels of schizotypy and social anxiety, and the influence of gaze orientation and social emotional action outcomes. The current chapter will introduce each of these areas of interest, outlining the current findings of such topics and how they may act as a cue in the generation of agency.

Mental and Physical Effort

Human action tends to be accompanied by muscular and proprioceptive cues, and also the sensation of effort. The sensation of effort for volitional actions may act as one cue of the self being agentic in the environment (Demanet et al., 2013; Lafargue & Franck, 2009). Effort can arise in the form of physical and mental exertion, both of which are two distinct sensations operationalised through motor control and cognition, respectively. Whereas physical effort is associated with muscular power, strength and action, mental effort is a psychobiological state associated with a sensation of exertion of ‘mental muscles’ for demanding cognitive activity (Bayne & Levy, 2006; Marcora, Staiano, & Manning, 2009; Vierkant, 2014). Despite their differences, mental and physical over exertion induce fatigue leading to reductions in physical performance (Boksem, Meijman, & Lorist, 2005; Marcora et al., 2009). Mental and physical effort also result in similar physiological arousal responses such as dilated pupillary responses, increased heart rate, increased oxygen consumption, greater energy consumption and increased respiration rate (Backs & Seljos, 1994; Beatty, 2008; Kahneman, 1973; Mehler, Reimer, Coughlin, & Dusek, 2009; Zenon, Sidibe, & Olivier, 2014). The similarities of effects are indicative of the cortical convergence of mental and physical effort and the use of common neurocognitive resources and systems, namely the autonomic nervous system (Marcora et al., 2009; Zenon et al., 2014).

The effects of mental and physical effort on cognition and perception.

Mental effort is understood as an index for cognitive load and expenditure of cognitive resources (Block, Hancock, & Zakay, 2010). Physical effort however, similarly puts strain on the cognitive system by expending cognitive resources for mental and sensorimotor representations and volitional control of the physical action, as well as to focus on meeting demands of the physical task (Epling, Blakely, Russel & Helton, 2016; Land, Volchenkov, Bläsing & Schack, 2013). Mentally taxing tasks implemented using dual task paradigms are also Under such circumstances in which the body is under physical or cognitive load performance on primary tasks reduces, such as proprioception, duration judgements, decision reaction times, decision making, self-regulation, and executive function (Abd-Elfattah, Abdelazeim & Elshennawy, 2015; Block, Hancock & Zakay, 2016; Dietrich & Sparling, 2004; Féry, Ferry, Hofe & Rieu, 1997; Vohs, Baumeister, Schmeichel, Twenge, Nelson & Tice, 2014). Mental and physical exertion also influence perception in other domains. For instance, perceived distance is increased and hills seem steeper to those who are less easily able to travel those landscapes, such as the elderly, those carrying a heavy load, and those who are fatigued (Bhalla & Proffitt, 1999; Sugovic & Witt, 2013). Throwing a heavy ball lengthens the perceived distance to a target compared to throwing a light ball (Witt, Proffitt, & Epstein, 2004), and distances to a target are perceived as longer when the floor is covered in a surface that is difficult to navigate (Sugovic & Witt, 2013). These findings are in accordance with the action–specific perception account (Witt, 2011), whereby the ease of ability to perform an action subsequently influences perceptions of the environment. Although the action-specific perception model accounts for action-related perception, this model maintains demonstrative of how the perceptual system can be influenced by the physical qualities of action, such as effort.

The effects of mental and physical effort on time perception.

When using a measure of time perception to investigate the sense of agency it is important to also note the effects that physical and mental effort may have on judgements of duration. The effects of physical load on interval judgements was recently examined in a meta-analysis revealing that physical load resulted in duration judgements to be elongated compared with the actual length (Block et al., 2016; seven studies spanning from 1963 – 2011). The impact of effort on perceived duration also goes beyond experienced physical load. Stimuli that imply motion, action, and exertion have also been found to elongate their perceived durations. The duration of images of ballet dancer statues are perceived as lasting longer, and the perceived duration of non-biological stimuli is lengthened when they are faster moving (Brown, 1995; Kaneko & Murakami, 2009; Nather, Bueno, Bigand & Droit-Volet, 2011). A meta-analysis examining the effect of mental effort also revealed that the reduction of cognitive resources, implemented through dual-task paradigms, resulted in longer retrospective time judgements (Block et al., 2010).

The role of cognitive resources for the attribution of agency

The attribution of agency expends cognitive resources in order to process motor predictions and sensory effects (Blakemore et al., 2001; Blakemore et al., 2002; Moore et al., 2009; Moore & Fletcher, 2012). Studies examining cognitive load, kinematics and motor awareness under contexts of dual-task paradigms reveal that cognitive and physical load disrupt balance, gait, posture and walking, and further cause reductions in motor control and motor awareness (Kannape, Barré, Aminian & Blanke, 2014; Lindenberger, Marsiske & Baltes, 2000; Woollacott & Shumway-Cook, 2002). The nature of these dual-task paradigms is such that motor control and cognitive activity compete for cognitive resources. This causes motor control and awareness to become less efficient due to cross-domain resource competition (Huxhold, Li, Schmiedek & Lindenberger, 2006; Lacour, Bernard-Demanze & Dumitrescu, 2008). The reduction of motor awareness caused by cognitive resource limitation is of crucial importance to the investigation of the sense of agency. Forward models of motor control are believed to be one process with which agency is ascribed. Inaccuracies or deficits in motor awareness would therefore cause a discrepancy in the comparison between expected and actual feedback of motor and sensory events and decrease the sense of agency. Cognitive resource limitation therefore has important implications for the construction of agency. During tasks which concurrently demand cognitive resources, the sense of agency may therefore be diminished.

Agency attribution under mental effort

The investigation of the effects of effort on a sense of agency are lessr studied, although there is some direct and indirect support for the role of mental effort reducing a sense of agency. Hon et al. (2013) studied the *explicit* sense of agency with a direct manipulation of mental effort. Participants reported the degree to which they felt agency over a dot which moved after a keypress. Participants were also under a concurrent working memory task. In this task participants were presented with a list of either six (high cognitive load) or two (low cognitive load) letters. At the end of the trial, after agency ratings, participants then recalled the letter in the list that followed the probe, i,e, if the probe was ‘X’, participants responded with the letter that occurred after ‘X’ in the list. Under conditions of high cognitive load, the explicit ratings of agency over a dot that moved following a key press were reduced, compared with low cognitive load conditions. These findings offer support for the diminishing role of cognitive resources on a sense of agency. However, this study investigated explicit judgements of agency.

Explicit and implicit measures of agency are found to be dissociated under some conditions (Dewey & Knoblich, 2014; Obhi & Hall; 2011) so there is value in converging evidence using an implicit measure of the sense of agency in adding further understanding to the role of effort and cognitive depletion of the sense of agency.

Some studies using implicit measures of the sense of agency also indirectly provide support for the role of mental effort reducing agency, although they do not directly address cognitive load. For instance, for socially negative outcomes and when the actor performs the action under coercion temporal binding is weaker (Caspar, Christensen, Cleeremans & Haggard, 2016, Yoshie & Haggard, 2013). Ratings of agency are also lower when distractor stimuli cause action selection conflict (Sidarus & Haggard, 2016). Each of these acts imply a significant degree of cognitive conflict which demands cognitive resources (see Greene, Nystrom, Engell, Darley & Cohen, 2004), and so these findings appear to be broadly complementary to the resource limitation effects on the ascription of agency proposed here.

Agency attribution under physical effort

Two recent studies have more directly investigated the effect of *physical* effort exerted during the action. Using an explicit measure of agency participants responded either ‘yes’ or ‘no’ as to whether they felt like that had caused an event (Minohara et al., 2016). Effort was manipulated by having participants push a button that required differing amounts of action-related force to do so, either low, medium or high force. Pushing the button resulted in a small square stimuli to jump upwards after delays from 100-1000ms (in increments of 100ms). The authors found that only at 700ms does the high force result in significantly greater attributions of explicit self-agency compared with low and medium force. The sensitivity of the effects of effort on explicit agency at 700ms was attributed to the uncertainty that the action caused the square to move due to reduced contiguity. It is suggested that the interoceptive cues of force acted as reliable indicators of agency at this critical time window. This sensitivity to temporal delays between the action and the effects may also reflect differences in the measure of agency. In this study participants explicitly reported whether they did, or did not, experience agency over the square moving. This reflects a judgement of agency, rather than feelings of agency measured using implicit temporal binding measures. Judgements of agency depend on retrospective inferences which rely more heavily on contiguity between action and outcomes to attribute agency.

Another study investigated the effect of physical effort on agency using an implicit measure (Demanet et al., 2013). Task-unrelated effort was manipulated such that the left arm was under strain by holding an exercise resistance band, whilst the right hand carried out the temporal binding measure using the Libet clock interval estimation paradigm. Demanet et al. found that temporal binding, and therefore implicit agency, was increased under greater task-unrelated physical effort. These findings, as are the findings of Minohara et al. (2016), are attributed to the theory that effortful actions are a cue to self-agency through the interoceptive sensory-motor information of willed effort (Haggard et al., 2002; Lafargue & Franck, 2009; Moore & Fletcher, 2012; Vierkant, 2014). The findings by Demanet et al. (2013) and Minohara et al. (2016) are consistent with the notion that physical effort acts as an indicator that the self is interacting with the environment. However, these findings are contrary to what would be expected considering the role of physical effort on the cognitive system, and the role of the cognitive system for the attribution of agency.

Agency and sensory attenuation

The detection of action related consequences

As previously discussed, the process by which we attribute agency is believed to function through predictive processes and forward models. Forward models make use of efference copies of the motor command to predict motor signals, as well as to predict the sensory effect as the result of such motor acts (Blakemore et al., 2001; Blakemore et al., 2002; David, Newen & Vogeley, 2008; Davidson & Wolpert, 2005; Synofzik et al., 2008; Wolpert, 1997; Wolpert & Ghahramani, 2000; Wolpert, Gharamani & Jordan, 1995).

A phenomenon that occurs as a result of motor and sensory predictions is that the salience of sensory stimuli is reduced, compared to externally generated sensory stimuli. For instance, ratings regarding the sensation of tickling are attenuated for self-tickling compared to externally sourced tickling (Bays et al., 2006; Blakemore et al., 1999; Blakemore et al., 1998; Blakemore et al., 2000), self-produced tones are experienced as being quieter than computer or other generated tones (Weiss et al., 2011), and ratings of intensity are reduced for somatic effects following voluntary movement compared with involuntary movement (Tsakiris & Haggard, 2003). It is believed that the forward model can also be initiated by the observation of an action through activation of the mirror neuron system as sounds are also perceived as quieter when they are generated by another individual (Sato, 2008). Sensory attenuation has also been confirmed neurally, with tactile stimuli, speech, tones, and visual stimuli generated as a result of self -action resulting in attenuated neural responses (Eliades & Wang, 2003; Haggard & Whitford, 2004; Hesse, Nishitani, Fink, Jousmaki & Hari, 2009; Hughes & Waszak, 2011; Jo, Wittman, Borghardt, Hinterberger, Schmidt, 2014; Martikainen, Kaneko & Hari, 2005; Poonian, Mcfayden, Ogden & Cunnington, 2015). It is believed that this sensory attenuation as a result of motor predictions is an adaptive phenomenon to dampen sensory processing for predicted sensory stimuli to save cognitive resources for the processing of other stimuli, such as unexpected events that may require attention and reaction to (Bays et al., 2006; Hesse et al., 2009). This notion is broadly supported by findings of reduced awareness of visual stimuli following self-generated changes (Berberian & Cleeremans, 2010).

Sensory attenuation of neuronal responses to effects of agency

Event-related brain potentials (ERPs) are measures of electrophysiological responses to a stimulus. They are measured using electroencephalography (EEG), a noninvasive method with which to detect electrical brain activity associated with neurocognitive processes using electrodes typically placed on the surface of the scalp (Luck & Kappenman, 2012). Although there are numerous ERP waveforms that stereotypically reflect neurocognitive components, of interest to the study of agency and sensory attenuation is the ‘readiness potential’, which reflects motor preparation neural activity, and the N1 and P2 waveform responses, which are sensitive to contexts of agency in the processing of action-outcomes.

The readiness potential. The readiness potential refers to transient negativity of slow cortical potentials that can start around 2 seconds before a conscious decision to act (Dirnberger, Fickel, Lindinger, Lang & Jahanshahi, 1998; Libet et al., 1983; Soon, Brass, Heinze & Haynes, 2008; for a review see Shibasaki & Hallett, 2006). The readiness potential is believed to reflect the initiation and preparation of actions and is a factor that contributes to the generation of agency . The readiness potential is therefore used as a measure to examine voluntary actions (Haggard, 2008; Shibasaki & Hallett, 2006). The degree of action preceding negativity in the early readiness potential (starting 2 seconds before initiation of the motor act), but not the late readiness potential (starting around 500ms before initiation of the motor act), has further been indicated to relate to the degree of implicit agency over an action related effect. For instance, greater slopes of negativity relate to the degree of temporal binding of the effect towards the action (Jo et al., 2014). Also, disrupting the pre-supplementary motor area, a structure involved in the conscious intention to act, reduces effect binding, but not action binding (Moore, Ruge, Wenke, Rothwell & Haggard, 2010). This indicates that the readiness potential contributes to temporal binding between actions and effects, and may have a crucial function in the degree of agency experienced over an action.

The auditory N1/P2 complex. The auditory N1 waveform is a negative component associated with the auditory ERP. It typically occurs 80 – 120ms following the presentation of auditory stimuli. The auditory P2 waveform is a positive deflection associated with the auditory ERP. It occurs following the auditory N1, the two components being known as the N1/P2 complex. The P2 has a maximum amplitude that occurs within a broad latency range of 150-275ms. Both the N1 and P2 waveforms are most detectable at the vertex, but are believed to originate in the auditory cortices (Sur & Sinha, 2009; Zouridakis, Simos & Papanicolaoul, 1998). In healthy individuals the amplitude of the N1 and P2 waveforms to a stimulus are reduced when the event is generated by self-initiated actions. For instance, the N1, and somewhat P2, ERP to auditory tones are reduced when initiated by a keypress compared with passive listening (Ford, Palzes, Roach & Mathalon, 2013; Horváth, Maess, Baess, & Tóth, 2012; Knolle, Schröger, Baess, & Kotz, 2012; Knolle, Schröger & Kotz, 2013; Kuhn, Nenchev, Haggard, Brass, Gallinat & Voss, 2014; Martikainen et al., 2005; Sowman, Kuusik & Johnson., 2012). Similarly, N1 amplitude is reduced for speech when vocalisations are self-generated (Ford et al, 2007; Timm et al., 2014). The amplitudes of the N1/P2 complex are therefore sensitive to contexts of agency, and neurally reflect the forward prediction model. Moreover, when a stimulus is repeated the amplitude of N1 is reduced (Grill-Spector, Henson & Martin, 2006). This reduction in N1 amplitude for repeated stimuli and amplitude attenuation of the N1/P2 complex for stimuli preceded by an action is believed to reflect sensory suppression, and therefore reduced sensory processing, of the stimulus, which is driven by predictive mechanisms (Bays, Wolpert, Haggard, Rosetti & Kawato, 2008; Hesse et al., 2009).

Sense of agency in schizophrenia

The sense of agency occurs so seemingly effortlessly and rapidly that the awareness of this may not even enter consciousness. However, this processing of the relationship between actions and their consequences can sometimes go awry. Examples of this can be observed in the symptoms of schizophrenia, whereby individuals attribute agency externally when events were in fact authored by the self, and vice versa.

Introduction to schizophrenia

One way to investigate behavioural phenomena is to study pathologies in which such phenomena are abnormal. One disease of which its symptoms are characterised by deficits in sense of agency is schizophrenia. Schizophrenia is a mental disease characterised by a vast range of symptoms typically separated into a category of positive or negative symptoms, or cognitive dysfunction. Schneider's (1959) First Rank Symptoms (FRS) describe a subset of positive symptoms relating to self-disturbances. For instance, passivity experiences, delusions of control, delusions of influence and auditory hallucinations. These FRS reflect disruptions of the sense of agency (Blakemore et al., 2002). There is evidence that the symptoms, onset and incidence of schizophrenia manifest differently across gender, and may be somewhat driven by hormonal differences (Häfner, 2003; although gender differences in schizophrenia are still under debate, see Häfner, 2003; Ochoa, Usall, Cobo, Labad Kulkarni, 2012). Compared to females, in males the incidence of schizophrenia is reportedly higher and the age of onset is earlier. Men also have higher levels of negative symptoms whereas women are more likely to suffer with affective and positive symptoms (Ochoa et al., 2012; Thorup et al. 2014). There is also some evidence towards gender differences in cognitive functions, with some studies reporting that men have more deficits in attention, language, executive function and memory compared to women (Ochoa et al., 2012).

Agency deficits in schizophrenia

Deficits in self-agency in schizophrenia may in part be a result of errors in motor awareness and motor prediction. Forward models of motor control explain that self-agency over an action occurs when motor predictions of the action and sensory consequences match. It is suggested that a mismatch due to the inability to create accurate predictions concerning sensory effects and outcomes of willed actions, causes a diminished sense of agency in schizophrenia. This mismatch is experienced as an external force exerting control and generation over movements (Blakemore & Frith, 2003; Frith, Blakemore & Wolpert, 2000; Wolpert et al., 1995). This deficit in motor prediction and motor awareness is apparent when comparing behaviour between schizophrenia patients and healthy controls. For instance, compared with healthy controls, patients were less able to distinguish between another's hand movements and their own (Dapratti et al., 1997; Garbarini et al., 2016), were less able to detect the rotation of the visual feedback of their own arm movements (Synofzik et al., 2010), and also responded to self-tickling as though it was sourced externally (Blakemore, Smith, Steel, Johnstone & Frith, 2000). It has been indicated that the deficit in motor prediction lies, at least in part, in the timing of its occurrence, whereby patients with schizophrenia process predictions in movement later than healthy controls (Koreki et al., 2015).

These errors in awareness of self-agency in schizophrenia are also demonstrated using explicit agency judgements. Patients with schizophrenia report greater agency ratings over another's hand movements (Daprati et al., 1997; Franck et al., 2001), and feel a greater sense of agency over visual stimuli movements initiated by button presses (Koreki et al., 2015; Maeda, Kato, Muramatsu, Iwashita, Mimura & Kashima, 2012). This latter effect, however, is typical of patients suffering with FRS of schizophrenia (Blakemore et al., 2002; Daprati et al., 1997; Franck et al., 2001; Maeda et al., 2012), and a reverse pattern, a decrease in ratings of agency, is observed for patients with negative symptoms of schizophrenia (Maeda et al., 2013). These data seem sensible since negative symptoms of schizophrenia manifest as a lack of affect, responsiveness and motivation, and also manifest as passivity. The latter two symptoms are especially relevant since they reflect the decrease in subjective agency experienced in individuals with schizophrenia.

Deficits in time perception in schizophrenia

As noted prior, patients with schizophrenia process the predictions regarding their motor awareness and reafferent copies later than in typical healthy individuals (Koreki et al., 2015). This deficit in motor prediction and awareness may be a result of a more general deficit in temporal coordination, time perception and causality. Indeed, compared with controls, individuals with schizophrenia are less able to judge temporal order or discriminate between interval lengths, and also replicate intervals of sound sequences at a faster pace than healthy controls (Braus, 2002, as cited in Gómez, Marín-Méndez, Molero, Atakan & Ortuño, 2014; Papageorgiou et al., 2013). Furthermore, this deficit in time perception for individuals with schizophrenia is enhanced for those with FRS compared to those without (Waters & Jablensky, 2009). This may suggest that abnormalities in temporal coordination cause deficits in motor prediction and awareness, which in turn results in the abnormalities in the ability to ascribe self-agency. These abnormalities then manifest as FRS, which as previously highlighted, are reflective of deficits in self-agency.

Temporal binding and schizophrenia

Typically, individuals demonstrate temporal binding between actions and their outcomes, and not between two unrelated events, a phenomenon that is believed to reflect a sense of agency over the outcome generating action (Haggard et al., 2002; Humphreys & Buehner, 2010; Poonian & Cunnington, 2013). Patients with schizophrenia however, demonstrate ‘hyper-binding’, whereby the delay between actions and effects is perceived as subjectively much shorter, compared with heathy controls (Haggard, Martin, Taylor-Clarke, Jeannerod & Franck, 2003; Voss, Moore, Hauser, Gallinat, Heinz & Haggard, 2010). This hyper-binding effect is also mirrored in healthy participants administered ketamine, a drug that produces perceptual disturbances akin to psychosis (Moore et al., 2012; Moore, Cambridge, Morgan, Giorlando, Adapa & Fletcher, 2013), and also, numerically (although not significantly) in patients at earlier stages of schizophrenia, those with putative psychotic prodrome (Hauser et al., 2011). These hyper-binding effects are possibly a result of prediction errors (Koreki et al., 2015), such that if motor awareness is constructed late the contiguity between the constructed action signals and the effect is much stronger. This would result in a closer perceived temporal proximity between action and effect, which would further be reflected in the hyper-binding observed in individuals with schizophrenia. This account of motor prediction error disrupting the function of the comparator model for the attribution of agency may not, however, completely account for agency deficits. Interestingly, it has been found that patients with schizophrenia also demonstrate temporal binding between two action-unrelated sequential tones (Haggard et al., 2003). In this case, there is no influence of motor prediction errors since there is no action for which to create motor signals. The effect of hyper-binding may therefore be a result of additive temporal binding due to incorrectly ascribing action unrelated events to the self and deficits in time perception causing further underestimation.

Examining schizotypy as a means to investigate agency deficits in schizophrenia

The symptoms associated with schizophrenia are considered to be fully dimensional and span across a continuum from unobtrusive schizophrenia-like symptoms to psychosis and schizophrenia spectrum disorders (Nelson, Seal, Pantelis & Phillips, 2013). By identifying personality traits and behaviours typical of schizophrenia, individual levels of schizotypy, or schizophrenia like traits, can be ascribed. These individual differences in schizotypy are considered a useful construct in understanding and studying schizophrenia spectrum disorders (Barrantes-Vidal, Grant & Kwapil, 2015). Although extrapolating evidence from subclinical samples to understand behaviour in disease is somewhat indirect and less valid, there are benefits of examining subclinical traits of schizophrenia. For instance, factors such as medication and comorbidities with other disorders which can mask effects can be avoided (Lenzenweger, 2010).

As already illustrated, individuals clinically diagnosed with schizophrenia demonstrate disruptions in the awareness and prediction of motor control, temporal coordination, and explicit judgements of sense of agency (Blakemore et al., 2000; Braus, 2002, as cited in Gómez et al., 2014; Daprati et al., 1997; Franck et al., 2001; Haggard et al., 2003; Koreki et al., 2015; Maeda et al., 2012; Maeda et al., 2013; Papagorgiou et al., 2013; Synofzik et al., 2010). These behaviours are also mirrored in those with high schizotypy like traits. For instance, schizotypy was positively correlated with abnormal motor control measured through movement prediction errors (Asai, Sugimori & Tanno, 2008), and weaker judgements of agency over the movement of a cursor was observed for individuals with high levels of schizotypy (Asai & Tanno, 2007). The only study that investigates implicit measures of agency and individual differences in schizotypy failed to find a significant relationship between their measure of schizotypy (magical ideation) and temporal binding (Dewey & Knoblich, 2014; but see Moore et al., 2011, for the investigation into surprise, sense of agency temporal judgements and schizotypy). However, schizophrenia is a complex disease so investigating schizotypal traits on one scale of magical ideation does not fully cover the extent of schizophrenia like experiences and behaviours, and thus may not capture the traits influential on the implicit time perception measure of agency.

Social responses to actions

The ability to determine effects in the world which are self-generated appears to be quickly and easily governed. This gives rise to a sense of agency over our actions which can be related to feelings of responsibility. Sometimes however, agency is experienced more strongly or is dampened when outcomes are not favourable. One possible context of this is when a consequence of an action causes an emotional effect in another individual. Imagine, for instance, generating an outcome which makes someone smile compared to one which makes someone cry. The sense of agency is likely stronger in contexts in which elicit positive responses. Whereas, actions which cause negative effects are more likely to rejected as being caused by the self, or they are more likely to induce a reduction in feeling responsible for such an outcome.

Affective coding models for agency

The attribution of self-agency is believed to be generated using an internal forward predictions model. More recently, this model has been extended to take into account the role of postdictive and reflective cues, which are weighted for their influence in determining self-agency depending on their salience and reliability (Synofzik, et al., 2008; Synofzik et al., 2013; Vosgerau & Synofzik, 2012). Some such cues are believed to be affective coding (Gentsch, & Synofzik, 2014).

Gentsch and Synofzik's (2014) 'affective coding of agency' model proposes three emotional determinants of agency: prospective, immediate and retrospective affective coding. Prospective affective coding proposes that affective state, trait or context variables influence prospective representations of a sense of agency. Immediate affective coding refers to fast and automatic processing of emotionally salient stimuli and bodily responses. Retrospective affective agency refers to post-hoc assessments of agency dependent on affectivity of the action outcome. Individual differences in affective style, such as tolerance, emotion regulation and affect suppression, can mediate the affective coding and how this is weighted for reliability in the ascription of agency. This may explain individual differences in the attribution of self-agency and also account for agency disruptions in affective disorders such as depression and schizophrenia.

Affective coding and time perception

Because the temporal binding measure of agency relies on time perception, it is important to consider how affect may influence this measure. As previously discussed, subjective time does not reflect objective time due to the lack of an objective measure with which to sample time. Internal and external contexts therefore influence duration judgements, with affect being one influential factor on perceived time. The role of affect on time perception has been vastly investigated and findings reliably report that negative stimuli result in the elongation of subjective time (for a review see Droit-Volet, Fayolle, Lamotte & Gil, 2014). For instance, faces, sounds and images evoking anger, sadness, fear and disgust all increase subjective time compared to neutral and positive stimuli (Bar-Haim, Kerem, Lamy & Zakay, 2010; Doi & Shinohara, 2009; Droit-Volet Brunot & Niedenthal, 2004; Gil & Droit-Volet, 2012; Grommet, Droit-Volet, Gil, Hemmes, Baker & Brown, 2011; Mella, Conty & Pouthas, 2011; Yamada & Kawabe, 2011). The effect of temporal dilation of negative stimuli are believed to be a result of an arousal based mechanism that speeds up the internal pacemaker clock system. The number of ticks accumulated by the pacemaker reflects subjective time, so when the speed of the accumulation of ticks quickens, more ticks are counted, and subjective time is elongated. This response may simply be a by-product of arousal preparing the body for a fight or flight response to threat, but may also act as a purposeful adaptive response to slow subjective time through making an experience longer for efficient response preparation (Droit-Volet & Meck, 2007).

The sense of agency and affect

The relationship between our emotional state and our actions is bidirectional (Gentsch & Synofzik, 2014). Our interactions with the world impact our emotional states and our emotions shape how we interact with the world. For instance responsibility and culpability over worldly outcomes may induce feelings of pride or shame, and feeling pride or shame facilitates the re-enaction or aversion, respectively, of the behaviour associated with the emotion. Affective disorders provide evidence of how strongly affect and action are linked. For instance, states of depression are accompanied with anhedonia, a sense of passivity, helplessness, incapacity, diminished experience of volition, and fewer interactions with the external world (Ratcliff, 2013). This pattern of results is also observed with implicit temporal binding measures of sense of agency whereby inducing a depressive mood in healthy participants results in reduced temporal binding of actions and outcomes (Obhi, Swiderski & Farquhar, 2013).

One mechanism as to why action and emotion may be influential on each other may be the self-serving bias (Greenberg, Pyszczynski & Solomon, 1982; Mezulis, Abramson, Hyde & Hankin, 2004). The self-serving bias refers to the inclination to attribute positive events to the self, and negative events to external factors. Its function is believed to be to maintain a healthy self-esteem (Greenberg et al., 1982; Mezulis et al., 2004). Indeed, humans have a proprioceptive bias towards positive stimuli. The position of pointing actions are perceived to be closer to positive stimuli compared to negative stimuli (Wilke, Synofzik & Linder, 2012). This bias for positive effects is also observed in the rejection of the association between the self and negative effects, whereby monetary losses as a result of action result in reduced agency (measured using temporal binding) over the action, compared with monetary gains (Takahata et al., 2012). However, one study manipulating the severity of the negative outcome to actions found that more severe consequences resulted in greater temporal binding (Moretto, Walsh & Haggard, 2011). These findings provide tentative support against the notion of the positive self-bias for agency since Moretto et al. did not examine positive effects to actions, so comparisons cannot be made. The degree of sense of agency ascribed to actions with outcomes of positive or negative affect may therefore reflect the level of association that actions have with the self. Sense of agency may therefore modulate the self-serving bias.

The sense of agency and socially relevant outcomes

Humans are highly social beings, endowed with brain structures that support complex social interactions (Adolphs, 2009; Blakemore, 2008). The relationship between our actions and their consequential effects for others is inherently influential in shaping our own behaviour. It is therefore important to consider the role of social responses for how individuals ascertain their sense of agency. Indeed, some recent studies have examined this with some mixed results. Yoshie and Haggard (2013) investigated the role of the valence of social emotional sound responses to actions. They found that negatively valenced social sounds decreased implicit sense of agency compared to neutral and positive sounds. These data complement the notion of distancing the self from culpability to negative events and may provide evidence for a second mechanism as for why actions and affect are intimately linked: to facilitate social interactions. This may function as an adaptive process to encourage future social interaction with positive consequences and dismiss actions with negative outcomes (Yoshie & Haggard, 2013). On the contrary, a close replication of Yoshie and Haggard by Christensen, Yoshie, di Costa and Haggard (2016) found that positively and negatively valenced sounds resulted in comparable temporal binding. Moreover, although not directly investigating the role of socially valent stimuli, Moretto et al. (2011) found that negative moral action outcomes did not modulate temporal binding differently to negative non-moral economic outcomes, whereas the increased severity of the negative outcome enhanced binding. These data then indicate that the role of socially valent outcomes to actions on the sense of agency is unclear.

The purpose of the thesis

Individuals perform actions which require varying levels of exertion, or under varying levels of cognitive strain, such as fatigue and stress, or whilst multitasking. Similarly, humans are complex social beings and perform actions in social settings, prompting emotional response outcomes. Individual differences in personalities are also found to influence the way in which the world is experienced. These factors can all be potential cues for the generation of agency, however, they tend to be omitted from investigation in the field of agency. The purpose of this thesis is to investigate the degree of agency ascribed in these varying contexts. This will allow us to ascertain whether these contexts afford cues that hinder the sense of agency, or whether agency remains robust to these contextual cues.

Physical and mental effort are known to pull on cognitive resources. The action monitoring system also requires cognitive resources. Of interest here then is whether the sense of agency is influenced by the availability of resources with which to monitor actions, or whether under such cognitive strain the alternative cues, such as the interoceptive cue of muscular force, is favoured for its weighting in agency attribution. To examine this, Chapter 3 investigates the role of physical effort which is both related (Experiment 1) and unrelated to the action (Experiment 2) over which agency is ascribed. Chapters 4 and 5 more directly investigate the role of cognitive resources on the sense of agency by concurrently administering a working memory task and the interval reproduction task. Chapter 5, in particular, examining the role of mental effort on the neural signatures of agency.

The sense of agency is also known to be disrupted in patients with schizophrenia, however, most examinations agency deficits focuses on judgements of agency and deficits in motor awareness. Schizophrenia is considered to be a fully dimensional disorder on a continuum from schizophrenia-like traits to psychosis. Chapter 6 focuses on subclinical levels of schizotypy and how this may modulate the sense of agency. Through this investigation, the disruptions of the sense of agency can be assessed across the scale of schizotypy to highlight the mechanisms which may bring about the agency deficits observed in schizophrenia.

Finally, the self-serving bias, which stipulates that individuals maintain a healthy self-esteem by associating themselves with positive outcomes and distancing themselves from negative outcomes, may provide a mechanism for which the sense of agency functions. Negative outcomes may therefore offer another context in which the sense of agency is disrupted, and may reveal another purpose of engaging in positive social engagement and dismissing negative social engagement. Chapter 7 investigates the role of socially relevant outcomes using valent facial expressions as a response to action.

In each experiment participants took part in an interval reproduction task whereby the interval between two events was to be reproduced with a depression of the spacebar for the duration of the perceived interval. The interval separated two events which differed dependent on the presence or absence of agency. The two events in conditions in which agency was present consisted of a self-generated keypress on the spacebar which was followed by a tone (Experiments 1-6) or a visual stimulus (Experiments 7-9). The two events in conditions absent of agency, in which no action was made, were either two tones (Experiments 1-6) or a tone and a visual stimulus (Experiments 7-9).

The investigation of manipulations to the motoric aspects of action, availability of cognitive resources and the action outcome throughout the experiments in this thesis aimed to elucidate circumstances in which the sense of agency can be hindered. These investigations also provide insight as to the importance of cognitive resource availability in addition to determining the influence of low-level sensory cues and high-level conceptual cues in the ascription of agency.

Chapter 3: Physical effort disrupts implicit sense of agency

It is important that the human motor system can efficiently process events which are the result of its own actions, and to discriminate these from events in the world for which it is not responsible. For instance, if I kick a ball and it knocks over and smashes a vase of flowers, I know my action of kicking the ball was responsible for the vase smashing. Self-authored events like this tend to be easy to identify and this feeling that 'I did it' is the manifestation of self-agency. Some actions are more effortful than others; kicking a ball as hard as one can might break a vase, but so might brushing one's arm against it as one walks past it precariously positioned near the edge of a table. Both these actions have the same outcome, but might require the action monitoring system to respond differently in order to correctly ascribe agency. Here, the role of physical effort on the ascription of sense of agency is investigated.

As reviewed in Chapter 2, physical effort depletes cognitive resources through the mental and sensorimotor representation of action, and the volitional online control of the action to meet the task demands (Epling et al., 2016; Land et al, 2013). This is especially important in the understanding of the effects of physical effort on the sense of agency, because the ability to ascribe a sense of agency is reliant on the availability of cognitive resources. This is because mechanisms which contribute to the sense of agency rely on comparisons between predicted and actual sensory effects to actions and their outcomes (Blakemore et al., 2001; Blakemore et al., 2002; Moore et al., 2009; Moore & Fletcher, 2012). Congruence between predictions and actual effects are believed to give rise to the sense of agency. On the other hand, incongruence between predictions and actual effects results in diminished agency. The comparisons between the sensory and motor predictions and effects further function as a result of motor awareness and control. When cognitive resources are available motor awareness and motor control is reliable and robust, meaning that accurate comparisons can be made and agency is likely ascribed. Whereas, when cognitive resources are limited the ability for the system to create an accurate representation of sensorimotor and proprioceptive signals is reduced, meaning that comparisons are made with an unreliable construction of motor and sensory signals (Kannape et al., 2014; Lindenberger et al., 2000; Woollacott & Shumway-Cook, 2002). In the latter case the sense of agency would be reduced. With this in mind the notion of cognitive resource limitation has important implications for the sense of agency, especially when agency attributions are made simultaneous to tasks which divert resources away from the process of agency attribution.

Beyond evidence of motor control and awareness being reduced under cognitive load, and its relative importance for the ascription of agency, there is some support for the idea that reduced cognitive resources result in a diminished sense of agency. For instance, direct and indirect manipulations of cognitive load demonstrate that both explicit agency ratings, and temporal binding measures of agency, reduce under instances of cognitive load and cognitive conflict (Caspar et al., 2016; Hon et al., 2013; Yoshie & Haggard, 2013).

As introduced in Chapter 2, to my knowledge only two studies directly investigate the effects of physical effort for its modulatory role on the sense of agency. Demanet et al. (2013) examined the role of task-unrelated effort on the implicit sense of agency. Levels of physical task-unrelated effort were manipulated so that the arm contralateral to the active hand used to carry out the time perception measure held an exercise resistance band. The authors used the ‘Libet clock’ method. In contrast to predictions one could derive from the reviewed research regarding effort, limited cognitive resources and agency, Demanet et al. found that greater effort *increased* temporal binding, therefore implying a stronger implicit sense of agency under conditions of high task-unrelated physical effort. These findings were attributed to the notion that effortful actions boost the interoceptive sensory-motor information of willed effort, which may act as a cue to self-agency (Haggard et al., 2002; Lafargue & Franck, 2009; Vierkant, 2014).

In a more recent study, Minohara et al. (2016) manipulated physical effort demands of the action by having participants push a button which required differing amounts of action-related force, low, medium and high force. After a delay of between 100 and 1000ms (in increments of 100ms) a stimuli on screen, a small square, moved upwards. Participants were asked to judge whether they has caused the square to move with their keypress, responding either ‘yes’ or ‘no’. Only at 700ms did the high force keypress result in significantly greater judgements of agency, compared with low and medium force. This may be reflective of explicit judgements of agency relying more heavily on contiguity as a cue for self-agency.

The findings of Minohara et al. (2016) and Demanet et al. (2013) accord with Maine de Biran’s hypothesis that force is directly related to causality (1805, as cited in Demanet et al.), and may identify physical effort as an internal signal for the cue integration theory of agency (Moore & Fletcher, 2012). Nevertheless, these findings are contrary to what is known regarding the effects of physical effort on cognition and motor awareness. Not only is physical effort shown to increase the durations of perceived intervals, but physical effort also depletes cognitive resources – elements crucial for motor control and awareness. With reduced motor control and motor awareness, agency is misattributed, which results in reduced temporal binding (Block et al., 2010; Block et al., 2016; Huxhold et al., 2006; Kannape et al., 2014; Wenke & Haggard, 2009). Hence, it might be expected that the opposite effect would be observed; that exertion would result in reduced – not enhanced - temporal binding.

It is possible that differences between the findings of studies examining physical effort on the attribution of agency and the expectations of effects according to the cognitive resource limitation account for agency proposed here may be accounted for by task differences. For instance, Demanet et al. (2013) examined the role of task-unrelated physical effort. It is possible that sensorimotor cues for agency may be sensitive to the strain only in the effector carrying out the agency manipulation, such that the effect of physical effort is action specific. Demanet et al. also employed the Libet clock method as the implicit temporal binding measure of agency. It is possible that physical effort disrupts the perception of positional judgments on the Libet clock such that they are perceived as occurring earlier. This may be a result of disrupted attention. Minohara et al. (2016), investigated the role of task-related effort, but examined this in relation to explicit judgements of agency. Explicit judgements of agency are believed to be constructed using retrospective judgements, rather than sensorimotor cues. The role of effort in this study may therefore be reflective of a different construct of agency (Dewey & Knoblich, 2014). Comparisons across implicit and explicit measures may therefore not be appropriate.

To provide evidence that can help to establish the role of physical effort as a contextual cue for the construction of implicit sense of agency, two experiments were conducted to examine the role of task-related (Experiment 1) and task-unrelated (Experiment 2) physical effort.

The experimental focus of Chapter 3

To determine whether physical effort modulates agency over actions and their outcomes, a temporal binding paradigm measuring implicit agency was used. In particular, an interval reproduction paradigm, previously demonstrated to successfully show temporal binding in agentic tasks (Buehner & Humphreys, 2009; Engbert et al., 2008; Humphreys & Buehner, 2010; Poonian & Cunnington, 2013), was used to measure implicit sense of agency. Experiments 1 and 2 investigated the role of task-related and task-unrelated physical effort on agency, respectively. In this way, Experiment 2 is a close replication of Demanet et al. (2013), except that here an interval reproduction method of intentional binding was used whereas they used the 'Libet clock' method. Experiment 2 investigates the role of task-related physical effort, like in Minohara et al. (2016), using an implicit measure to do so, whereas Minohara et al. measured explicit judgements of agency.

Given the diminishing effects of physical effort on cognitive resources, it can be predicted that high physical effort will result in a decrease in temporal binding in agentic conditions. However, the only previous studies to investigate physical effort and sense of agency, found the converse effect, that high effort increased implicit and explicit agency (Demanet et al., 2013; Minohara et al., 2016). The current investigation therefore also aims to clarify whether there is a general effect of effort on agency, or whether the specific context and source of the effort plays a critical role in the extent to which an implcit sense of agency is generated.

Experiment 1: Task related physical effort

Experiment 1 was designed to test the effects of task-related effort on implicit sense of agency. Participants made temporal reproductions of intervals between their action (depression of a key) and the consequence (a tone) whilst under low or high task-related physical effort, i.e. the arm under effort was the arm performing the actions and interval reproduction task. If effort acts as a cue that the self is acting in the environment, and therefore increases the sense of agency that the action generates, then greater temporal binding between actions and consequences whilst under high effort are expected. Alternatively, if effort depletes cognitive resources responsible for generating the agency signal, then more effortful actions will produce weaker temporal binding. Participants were also asked to provide ratings of the subjective effort they exerted under low and high effort in order to allow us to examine relationships between subjective effort and agency.

Method

Participants

Thirty-five participants aged 18-51 years (*M* = 22.2 years, *SD* = 7.79; six were men) were recruited from the University of East Anglia and completed the experiment in return for payment or course credit. Participants gave informed consent and were naïve as to the research question. Because the experiment involved exertion while holding a latex exercise band, individuals with a latex allergy, or back, neck, arm or shoulder pain were excluded from participation. No participants met these exclusion criteria. The study was approved by the School of Psychology Research Ethics Committee, University of East Anglia.

Apparatus & Stimuli

Physical effort was manipulated using Thera-Band® latex resistance bands which are typically used for exercise. The levels of effort were operationalised using two different resistance bands. This allowed for Low and High effort conditions using Thera-Bands® in colours yellow and blue, respectively. The amount of force required to hold the bands in the required position was approximately 24.5N and 4.9N for the high and low effort bands, respectively. The bands were attached to a handrail that was fixed to the wall behind the participants, 94cm from the ground, positioned off to the right so that the band was pulled past the participant's trunk and held in the right hand over the space bar.

The position of the keyboard from the centre of the space bar was approximately 40 cm from the front edge of the table. The height of the table was 71 cm. A tone (150ms, 440Hz; created using Audacity® software) was presented using Logitech speakers. Visual stimuli were presented (black text on a white background) using *E-Prime*® software on a Dell 1909W monitor (size: 19 inches; resolution: 1440 x 900; refresh rate: 60 Hz).

Design

In a 2 x 2 repeated measures design participants completed four experimental block types differing across two factors: Presence of Agency (Agency and No Agency) and Physical Effort (Low and High). The dependent measure was duration reproduction error, derived as the actual interval minus the reproduced interval (ms). Participants also rated how much effort they experienced whilst holding the low and high effort bands in the required position both before (Pre) and after (Post) the experimental blocks (scale from 1-10; 1 indicating low effort). Additional variables were also calculated: Effort Differential: the difference in effort ratings that participants gave to the low and high effort bands (averaged over ratings they gave pre- and post-experiment [High Effort – Low Effort]); and Reproduction Error Differential: the difference in reproduction error between agency and no agency conditions under high vs. low effort conditions (i.e. [Agency High – No Agency High] – [Agency Low – No Agency Low]).

Procedure

Presence of Agency manipulation. Instances of agency were manipulated using an Interval Reproduction task (Humphreys & Buehner, 2010; Poonian & Cunnington,

2013) in which participants were instructed that a tone would occur after a first event: either a self-initiated spacebar press with their index finger (Agency) or after a first auditory tone (No Agency). The stimulus interval was the delay between the first event and the outcome (randomised between 500-1500ms; as in Humphreys & Buehner, 2010; Poonian & Cunnington, 2013). The mean length of the jittered stimulus interval was comparable in the four conditions across the Presence of Agency and Effort manipulations, Fs < 2.8, ps > .1. Participants were immediately prompted to make response intervals by depressing the spacebar with their index finger for the duration they perceived the stimulus interval to have lasted, after which a fixation cross was presented for 1000ms and the trial ended (see Figure 2 for the Interval Reproduction task procedure).

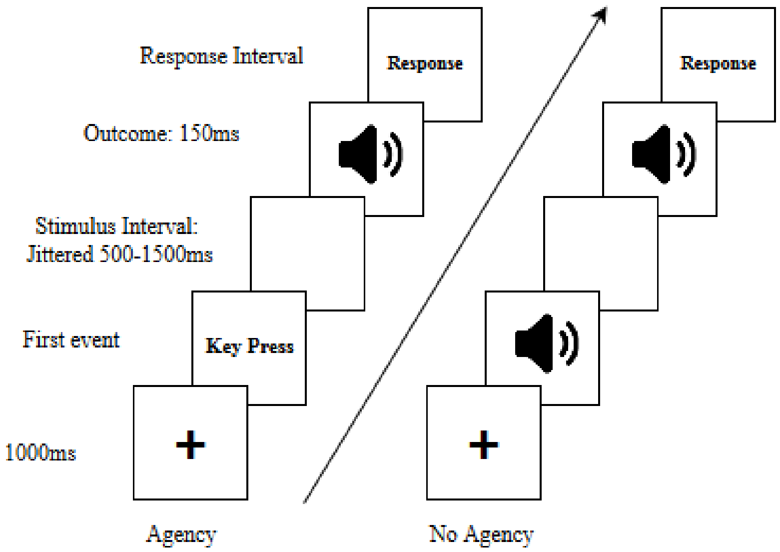

Figure 2. Procedure for the Interval Reproduction task. In each condition the first event consisted of either a key press (Agency) or a tone (No Agency). After a randomised stimulus interval (500-1500ms) the outcome, a tone, was presented. Participants were prompted to respond by recreating the interval between the first and second events with the depression of the spacebar.

Effort manipulation. Throughout the interval reproduction task the level of physical effort was manipulated by having participants hold the end of a resistance band (Low or High) with their right hand, in a fixed position with their arm outstretched towards the spacebar which sat approximately 40cm from the table edge. This allowed for *task-related* induction of effort (task-unrelated effort is investigated in Experiment 2; see Figure 3 for the effort manipulation set-up). Participants were instructed before each block of trials as to which band to hold. After each block participants were encouraged to take self-paced rest periods.

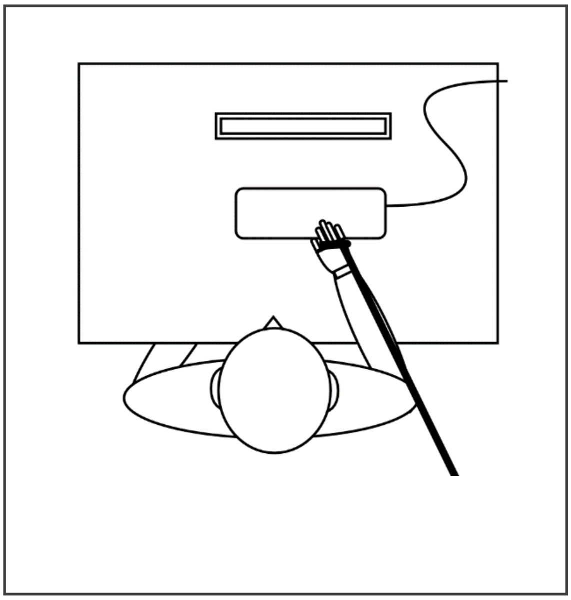

Figure 3. Effort manipulation set-up. Participants held the exercise band in their right hand for task-related physical effort.

Before starting the experiment participants completed a short practice block involving the Presence of Agency and Physical Effort manipulations. The experiment consisted of eight blocks (two blocks per condition) of 20 trials per block. Each experimental condition therefore contained 40 trials. Condition order, manipulated across blocks, was counterbalanced so that one block of each condition was presented in the first half (blocks 1-4) and the second half of the experiment (blocks 5-8). The blocks in the first half of the experiment were counterbalanced with each possible order run through. The blocks in the second-half backwards mirrored the condition order in the first half. The experiment comprised 160 trials and typically took approximately 45 minutes.

Effort manipulation check. The effort manipulation was successful. This was confirmed by examining the effort ratings that participants gave to each band before and after the experiment in a 2 (Physical Effort; Low and High) X 2 (Time; Pre and Post) ANOVA. The main effect of 'Physical Effort' was significant, $F(1, 34) = 522.76$, $p < .001$, $\eta p^2 = .94$, due to higher effort ratings for the High compared with the Low effort resistance band ($M = 6.83$, $SD = 1.38$ and $M = 2.26$, $SD = 0.71$, respectively). The main effect of 'Time' was not significant, $F(1, 34) = 1.4$, $p = .25$, $\eta p^2 = .04$. The interaction was significant, $F(1, 34) = 33.18$, $p < .001$, $\eta p^2 = .49$, because the difference in ratings between high and low effort bands was larger after, compared with before, the experiment (Low effort band: Pre: $M = 2.49$, $SD = 1.01$; Post: $M = 2.03$, $SD = .82$; $t(34) = 2.31$ $p = .027$, $d_z = 0.39$; High effort band: Pre: $M = 6.43$, $SD = 1.46$; Post: $M = 7.23$, $SD = 1.46$; $t(34) = 4.91$ $p < .001$, $d_z = 0.83$).

Results

Trials with extreme reproduction errors were removed (0.48% of trials; determined for all experiments as trials that exceed +/- 3SD from the mean of all trials across conditions, per participant). Mean reproduction errors for each participant in each condition (Figure 4) were analysed using a 2 (Presence of Agency) X 2 (Physical Effort) ANOVA, revealing significant main effects of both of these factors: $F(1, 34) = 54.54$, $p < .001$, $\eta p^2 = .62$, and $F(1, 34) = 14.43$, $p = .001$, $\eta p^2 = .3$, respectively. These main effects were due to larger reproduction errors - more underestimation - in the Agency condition than the No Agency condition, (M = -322ms, SD = 236 and M = -56ms, SD = 265, respectively). This replicates the basic temporal binding effect (Buehner & Humphreys, 2009; Haggard et al., 2002; Humphreys & Buehner, 2010; Poonian & Cunnington, 2013). There were larger reproduction errors in the Low effort compared with High effort conditions, M = -208ms, SD = 230 and M = -170ms, SD = 228, respectively. However, the critical interaction was non-significant, $F(1, 34) = 2.12$, $p = .154$, $\eta p^2 = .06$.

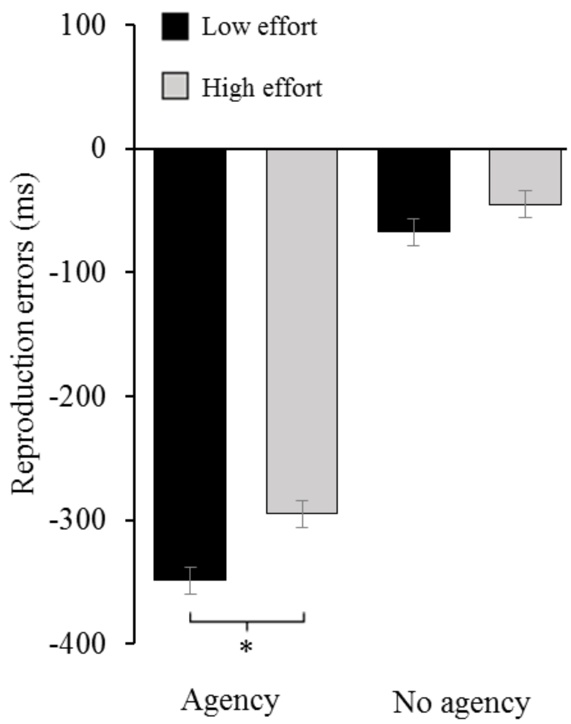

Figure 4. Mean reproduction errors across factors Presence of Agency and Effort for Experiment 1. Bars extending below the x-axis reflect an underestimation of the stimulus interval (temporal binding). In all instances throughout this thesis the error bars represent the standard error of the mean for within-subject designs calculated using the procedure recommended by Loftus & Masson (1994) and asterisks indicate significant contrasts at $p<.05$.

Although the interaction – critical to the research question – was non-significant, two planned contrasts were nevertheless performed to investigate the nature of effects across Presence of Agency and Physical Effort. In the Agency condition, reproduction errors were significantly larger under Low than High effort, $t(34) = 3.46$, $p = .001$, $d_z = 0.589$, while this effect was not significant in the no agency condition, $t(34) = 1.59$, $p = .122$, $d_z = 0.27$. Therefore, due to a non-significant interaction, the overall results do not support the hypothesis that reproduction errors in agency tasks would be reduced under greater physical effort.

As a supplementary analysis, it was considered that individual susceptibility to the effort manipulation may play a critical role in determining the extent to which task-related effort might influence the implicit sense of agency. The relationship between Effort Differential scores and Reproduction Error Differential was therefore examined. A Pearson correlation revealed a significant positive relationship between the two variables, *r*(33) = .523, *p* = .001 (see Figure 5), whereby as Effort Differential increases, so does Reproduction Error Differential. This correlation was also significant when only considering the mean High Effort ratings, *r*(33) = .46, *p* = .005, but not when considering the mean Low Effort ratings, *r*(33) = .028, *p* = .88. This means that only participants who felt the difference in effort they were exerting also showed an effect of effort on the implicit measure of agency, with the ratings for high effort driving the effect. Overall, therefore, although the key interaction in the analysis was non-significant, this correlation clearly shows that this was related to the individual perception of the effort itself.

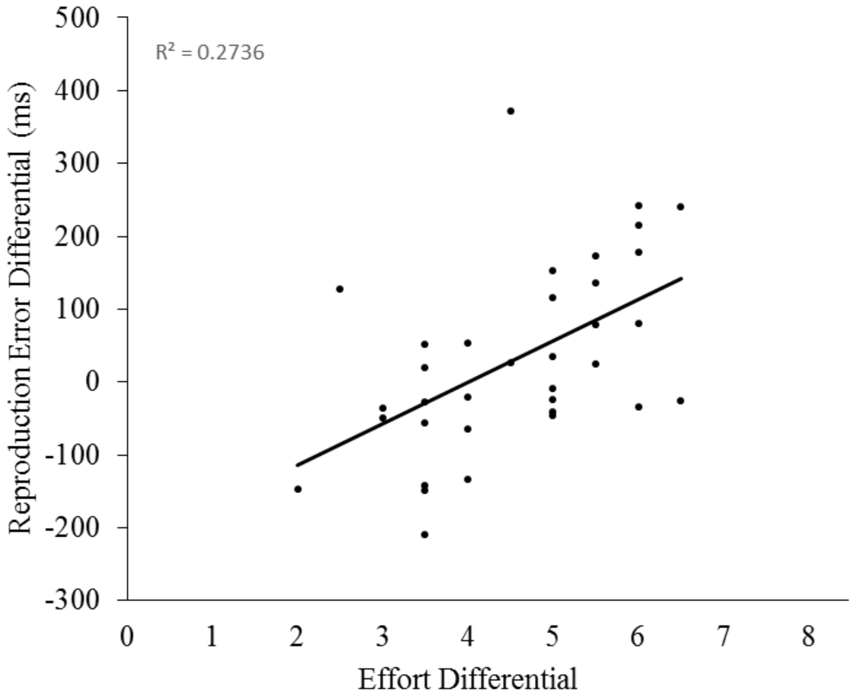

Figure 5. The relationship between Effort Differential and Reproduction Error Differential. As Effort Differential increases Reproduction Error Differential increases. Cases with reproduction error differential values above zero are individuals who showed stronger effects of agency (vs. no agency) in low than high effort conditions.

Finally, briefly reported here is a further analysis (as suggested by a reviewer for the paper Howard, Edwards & Bayliss et al., 2016, Appendix 1, who we would like to thank for the idea) which indicates an important role of duration of effort on agency. Specifically, it was found that the reduction of temporal binding under high effort was stronger during the second half of trials (i.e. after the arm had been under strain for some time) than in the first half. This finding was supported by the outcome of a 3-way

ANOVA with Presence of Agency, Effort, and the new factor Time on Task (1st half of trials vs. 2nd half of trials) as within-subject factors which is presented in Figure 6. The critical three way interaction was significant, $F(1, 32) = 5.73$, $p = .023$, $\eta p2 = .152$. Next, to confirm the source of this 3-way interaction, 2-way ANOVAs were conducted on the two halves separately. The 2-way interaction was not significant during the 1st half of trials, $F(1, 33) = 1.39$, $p = .248$, $\eta p2 = .04$ (like in the overall analysis above). However, the interaction was significant for trials in the 2nd half of the experiment, $F(1, 32) = 4.473$, $p = .042$, $\eta p2 = .123$. This was due to reduced reproduction errors under high effort compared with low effort in Agency conditions, $t(33) = 4.52$, $p < .001$, $dz = 0.78$ (M = -354. SD = 274 and M = -260, SD = 283, respectively). In No Agency conditions this effect was not observed, $t(33) = 1.38$, $p = .177$, $dz = 0.24$ (M = -47, SD = 286 and M = -24. SD = 287, respectively. It therefore appears that the effect of high effort on temporal binding increases with time on task.

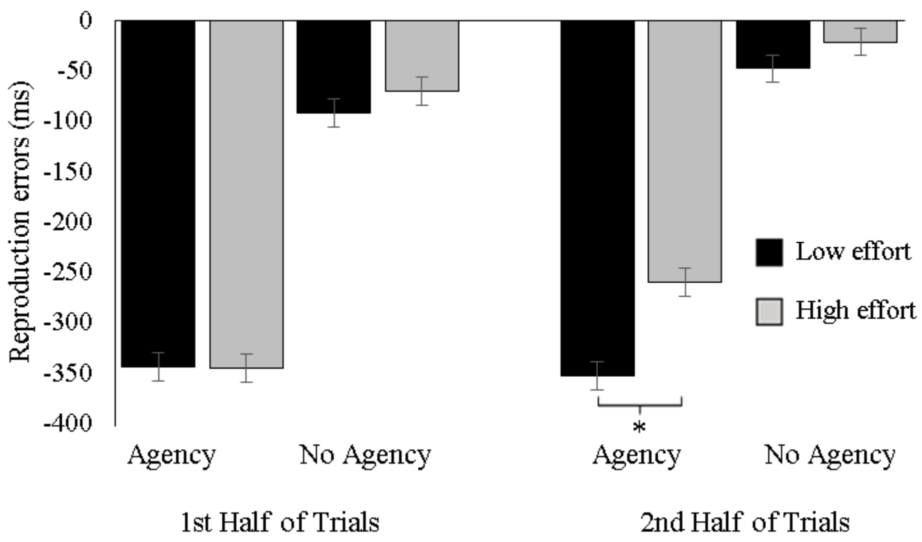

Figure 6. Mean reproduction errors across factors Presence of Agency, Effort and Time on Task for Experiment 1. Bars extending below the x-axis reflect an underestimation of the stimulus interval (temporal binding). In the second half of trials, reproduction errors were reduced under high effort in Agency conditions only.

Discussion

Overall, the data indicate agency effects in that there was greater temporal binding during conditions in which agency was present, replicating previous work (Buehner & Humphreys, 2009; Engbert et al., 2007; Engbert & Wohlschläger, 2007; Haggard et al., 2002; Humphreys & Buehner, 2010). However, there was no reliable difference in the effect of agency on interval reproduction errors across different levels of effort. Nevertheless, although the critical interaction was indeed non-significant, the contrast between effort levels in agency conditions was significant, but in the opposite direction to that found by Demanet et al. (2013). Specifically, there was stronger binding (which implies greater implicit sense of agency) under low effort than under high effort. This discrepancy with Demanet et al's finding could be explained by the difference in how implicit agency was measured. Here an interval reproduction paradigm was used, whereas Demanet et al. used the Libet clock method. It is not clear what aspect of these two methods might result in such divergent findings, however, it is considered that the resource depletion characteristic of high effort conditions under agency may have disrupted attentional focus on the positional judgement of the outcomes on the Libet clock. Another key difference between the procedure used here and that of Demanet and colleagues is that the present Experiment 1 involved the participants engaging in task-related effort (the hand used to act was under strain) whereas a passive arm was under strain in Demanet et al. In Experiment 2 whether this latter difference accounts for the disparate findings is examined by having the participants engage in task-unrelated effort, like Demanet and colleagues' participants.

Although the critical agency by effort interaction did not approach significance at the group level, a significant medium-sized effect was found when investigating individual appraisals of exertion. Participants who experienced the high effort manipulation as much more exertive than the low effort manipulation demonstrated a larger disparity in binding difference across the low and high physical effort conditions. A medium-sized effect was also found when investigating the build-up of fatigue, such that in the second half of the experiment temporal binding was reduced under conditions of agency under high effort. Therefore, reasonably strong conclusions can be drawn from these data overall despite the lack of a clear effect at the group- and full session-level: high effort did reduce the sense of agency, on an individual difference level for those who registered the exertion as more effortful than the low effort condition, and also on a group level in which this effect was observed in the second half of the experimental session. It is noted again here, that these findings are in the context of task-related physical effort, so it is important to establish whether these effects (in particular the individual differences effect) are specific to task-related effort. Therefore, in addition to testing conditions closer to Demanet et al. by using task-unrelated effort, Experiment 2 also allows us to examine again the influence of individual-level experience on the modulatory impact of effort on the sense of agency.

Experiment 2: Task-unrelated physical effort

Experiment 2 aimed to investigate whether modulations of temporal binding by effort are limited to task-related effort (Experiment 1) by making the effort in this experiment unrelated to the interval reproduction task performance. To do so, participants in this experiment held the band with the hand contralateral to the hand carrying out the interval reproduction and agency task. If temporal binding is affected by general experience of physical effort, that need not be undertook as a necessary part of the action creating the cause-effect outcomes in the environment, then results similar to Experiment 1 are expected. That is, high task-unrelated effort reduces temporal binding between action and effect. Alternatively, if there is something action-specific about the nature of the effort – task-related compared with task-unrelated – then a reverse pattern may be shown, replicating Demanet et al.'s (2013) finding of greater binding under high effort.

Method

Participants

Thirty-five participants (7 men; age range 18-54, $M = 21.26$, $SD = 6.28$) were recruited from the University of East Anglia and completed the experiment in return for payment or course credit. Participants gave informed consent and were naïve as to the research question. As the experiment involved exertion while holding a latex exercise band, individuals with a latex allergy, or back, neck, arm or shoulder pain were excluded from participation. No participants were excluded from participation due to this criteria.

Apparatus, Design and Procedure

The only alteration compared with Experiment 1 was that the resistance band was held in the left hand to allow for task-unrelated physical effort. Participants still responded to the interval reproduction task with their right hand, as in Experiment 1. The mean length of the jittered stimulus interval was comparable in the four conditions across the Presence of Agency and Effort manipulations, Fs < 1.5, ps > .71. The band was attached to a handrail fixed to the wall 94 cm from the ground on the left hand side of the participant. The band was pulled with the left hand towards the left side of the keyboard until the wrist was in line with the spacebar. The band was held in this position for the entire block of trials (see Figure 7 for the set-up of the task-unrelated physical effort manipulation).

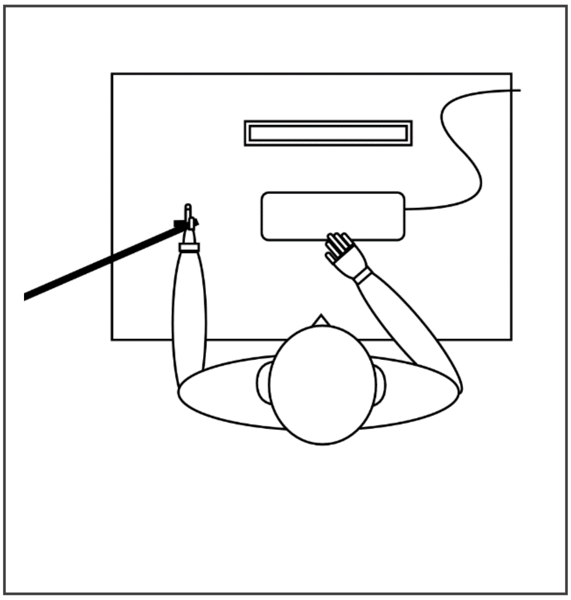

Figure 7. Effort manipulation set-up. Participants held the exercise band in their left hand for task-unrelated physical effort.

Effort Manipulation Check. The effort manipulation was successful, as confirmed by the same analysis as in Experiment 1. The main effect of 'Physical Effort' was significant, $F(1, 33) = 251.97$, $p < .001$, $\eta p^2 = .88$ (High: $M = 5.97$, $SD = 1.47$; Low: $M = 2.02$, $SD = .68$). The main effect of Time was significant, $F(1, 33) = 5.8$, $p = .022$, $\eta p^2 = .15$, because effort ratings were higher after than before the experiment ($M = 4.18$, $SD = .91$; $M = 3.81$, $SD = 1.06$, respectively). The interaction was also significant, $F(1, 33) = 21.83$, $p < .001$, $\eta p^2 = .4$ because the difference between high and low effort ratings was larger after the experiment than before (High: $t(33) = 4.12$ $p < .001$, $d_z = 0.71$; Post $M = 6.38$, $SD = 1.52$, Pre $M = 5.56$, $SD = 1.64$; Low: $t(33) = .55$ $p = .59$, $d_z = 0.1$; Post $M = 1.97$, $SD = .8$, Pre $M = 2.06$, $SD = .85$.

Results

A total of 0.55% of trials were removed as outliers. One participant was further removed for having extreme mean reproduction errors. The remaining data were submitted to the same analysis as in Experiment 1 (see Figure 8). This revealed a main effect of Presence of Agency, $F(1, 33) = 65.98$, $p < .001$, $\eta p^2 = .67$, with larger reproduction errors during Agency compared with No Agency conditions (M = -273ms, SD =189, and M = 24ms, SD = 252, respectively). The main effect of Physical Effort was also significant, $F(1, 33) = 5.03$, $p = .032$, $\eta p^2 = .13$, with smaller reproduction errors under High than Low effort (M = -106ms, *SD* = 205; M = -143ms, *SD* = 198, respectively). Critically, and unlike Experiment 1, the interaction between these factors was also significant, $F(1, 33) = 4.16$, $p = .049$, $\eta p^2 = .11$. Planned contrasts revealed that in No Agency conditions there was no difference between the effort conditions, $t(33) = .62$, $p = .542$, $d_z = 0.11$. Whereas, in Agency conditions High effort resulted in smaller reproduction errors compared with Low effort, $t(33) = 2.94$, $p = .006$, $d_z = 0.5$.

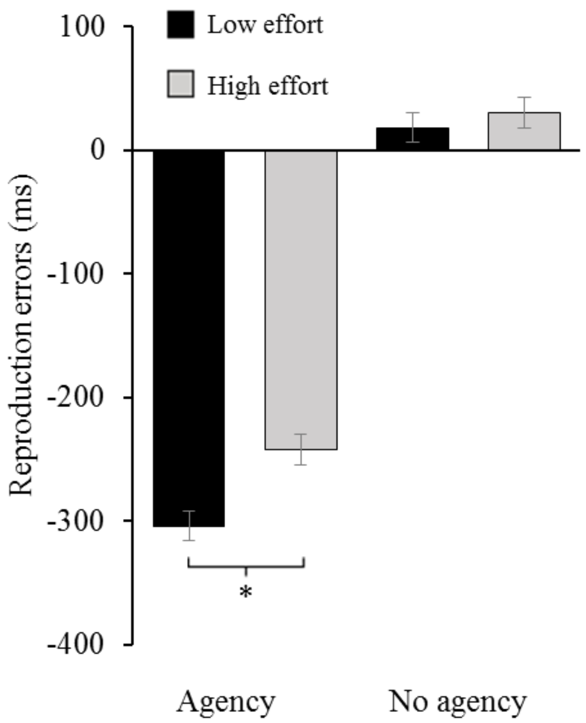

Figure 8. Mean reproduction errors across factors Presence of Agency and Effort for Experiment 2. Bars extending below the x-axis reflect an underestimation of the stimulus interval (temporal binding).

Similarly to Experiment 1, the relationship between the difference in effort ratings participants gave under the high vs. low effort conditions and the binding difference between agency and no-agency conditions in the low effort condition relative to the high effort condition was examined (see Figure 9). The correlation was not significant whether the mean of the pre- and post-experiment ratings were used, $r(32) = -.147$, $p = .407$, or if the mean High and Low ratings were used, $r(32) = -.201$, $p = .254$, and $r(32) = -.12$, $p = .5$.

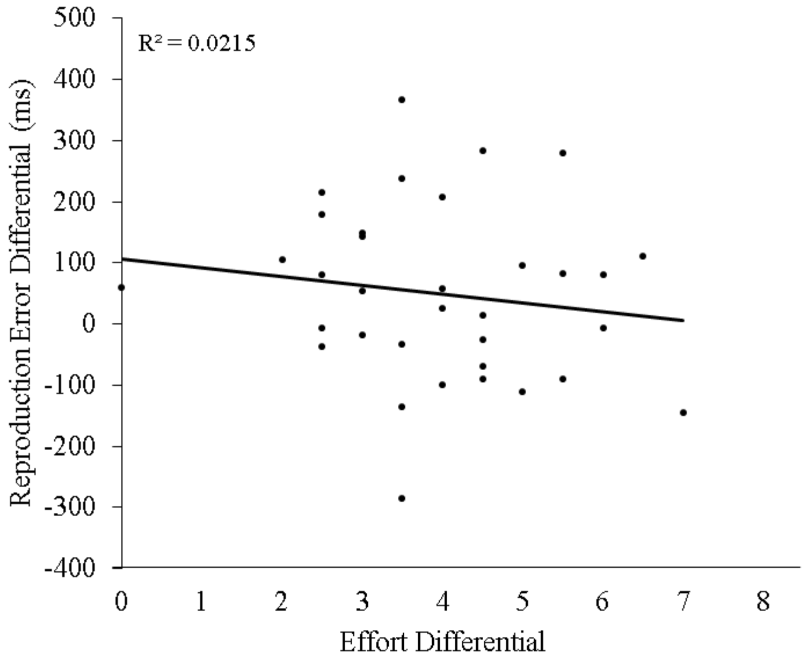

Figure 9. The non-significant relationship between Effort Differential and Reproduction Error Differential.

This stands in stark contrast to the findings of Experiment 1 where there was a moderate and significant relationship between the two variables, whereby the effect of effort on implicit agency was related with the explicit ratings of exertion. The correlation coefficients from Experiment 1 (r =.523) and Experiment 2 (r = -.147) differ significantly from one another (z = 2.89, p = .004).

As in Experiment 1, the effect of the factor 'Time on Task' in the first half of the session was compared with the second half. The three-way interaction was non-significant, $F(1, 33) = 1.41$, p =.24, $\eta p2$ = .041, indicating that unlike Experiment 1, the effect of effort on temporal binding was consistent through the experimental session.

Discussion

The general finding of temporal binding under conditions of agency was again replicated (Buehner & Humphreys, 2009; Engbert & Wohlschläger, 2007; Engbert et al., 2007; Haggard et al., 2002; Humphreys & Buehner, 2010), and this effect was weaker under high effort, even though the effort was task-unrelated. In Experiment 2, this effect of effort on binding was reliable at the group level (i.e. the critical effort by agency interaction was significant), but there was little role for individual appraisal of the subjective effort required, and was constant across the session, unlike in Experiment 1.

Notably, the data here are in the opposite direction to that observed by Demanet et al. (2013).

General discussion

The current study investigated the role of both task-related and task-unrelated physical effort for the modulation of implicit sense of agency. Using an interval reproduction paradigm, the amount of temporal binding between events in an agentic context (a self-made action and a consequent tone) compared with events which were not agentically related (two tones), was measured. Interval reproductions that are shorter than the actual length of the interval represent temporal binding between the events, whereby the events are perceived as closer together - ‘bound’ - in time. This measure is thought to be a valid implicit measure of the degree of agency that the cognitive system ascribes to a given event (Engbert et al., 2007; Engbert & Wohlschläger, 2007; Haggard et al., 2002; Moore & Obhi, 2012). In each experiment, temporal binding was greater under conditions of agency, but not under passive conditions, replicating prior work (Buehner & Humphreys, 2009; Engbert et al., 2007; Engbert & Wohlschläger, 2007; Haggard et al., 2002; Humphreys & Buehner, 2010; Moore & Obhi, 2012). Of critical interest was whether task-related (Experiment 1) and task-unrelated (Experiment 2) physical effort would modulate this effect of agency on temporal interval reproduction.

Overall, the data revealed that in conditions of agency temporal binding was weaker under high, compared with low effort (however, note that for Experiment 1, the key interaction was non-significant). This effect was not observed for conditions absent of agency. In general terms, this effect was consistent across experiments and statistical effect sizes were small to medium for the key interactions and correlations (Experiment 1 – key correlation r = .52; Experiment 2 – key interaction η_p^2 = .11) and small to medium for the key contrasts (Experiments 1 and 2 d_z’s 0.26 and 0.50, respectively). It is also worth noting that the key interaction in Experiments 2 reached the conventional .05 p-value threshold by a rather small margin, which suggests that although the sample size was calculated as sufficient to reveal the predicted effect sizes, future replication attempts may benefit from a larger sample to detect and confirm these small to medium statistical effect sizes.

Potential mechanisms for reduced sense of agency under physical effort

Here it was found that high effort resulted in a perceived shortening of the time between actions and their consequences (in Experiment 1 this effect was modulated by the subjective experience of effort). Importantly, this effect was not observed for conditions in which agency was not present. Across each of the experiments it can be assumed that the high physical effort condition indirectly drew on cognitive resources (Block et al., 2016). Cognitive resources are spent in physical activity in order to maintain mental and sensorimotor representation and volitional control of the physical action, and to focus on meeting demands of the physical task (Epling et al., 2016; Land et al., 2013). If agency ascription is itself cognitively costly, for reasons explained below, then under conditions of compromised cognitive resource availability, such as high physical effort, temporal binding would be weaker. This is because there are less resources to dedicate to agency signal generation due to resource depletion during effort exertion. Indeed, such reductions in temporal binding have been previously observed in conditions characteristic of cognitive conflict, such as coercion and negative social emotional consequences (Caspar et al., 2016; Yoshie & Haggard, 2013).

Dual process accounts of cognitive and motor control also lend indirect support for this cognitive resource competition theory for sense of agency (Huxhold et al., 2006; Lacour et al., 2008). Cognitive loading causes a reduction in balance and movement accuracy due to limited cognitive resource availability for motor awareness (Kannape et al., 2014; Lindenberger et al., 2000; Woollacott & Shumway-Cook, 2002). According to internal forward models of motor control, self-agency over an action occurs when motor predictions of the action and sensory consequences match (Blakemore et al., 2001; 2002). It is proposed that reductions in motor awareness caused by limited cognitive resources, interfere with the ability of the agency ascription system to create accurate predictions concerning sensory effects and outcomes of willed actions. This then results in a diminished sense of agency. Therefore, when cognitive resources are diminished, in the current case, by physical strain, resources are less available to generate accurate motor awareness, which in turn hinders the ascription of self-agency. The reduction of temporal binding under high effort in agency conditions in Experiments 1 and 2 may be demonstrative of this mechanism.

Action-specific effort effects

Overall, the data suggest that there may be a general effect of effort on implicit sense of agency, whereby high effort reduces temporal binding. However, for action specific effort (Experiment 1) this effect is dependent on the subjective experience of effort and effort induced fatigue. That is, for those under task-related physical effort, the more effort experienced, either for individual differences in subjective effort experienced, or for task induced fatigue over time, the stronger the deleterious effect of high effort is on temporal binding. This modulation of individual appraisals of effort may endorse the cognitive resource depletion account suggested. Whereby, high effort (or - in the case of Experiment 1 - those who experience the action specific effort as highly effortful), depletes cognitive resources otherwise used for enhancing motor awareness. This reduction in motor awareness further interferes with agency ascription and temporal binding (Blakemore et al., 2001; Blakemore et al., 2002; Kannape et al., 2014; Lindenberger et al., 2000; Woollacott & Shumway-Cook, 2002). Subjective task difficulty has been shown to be related to effort expenditure (Ennis, Hess & Smith, 2013). Those who experienced the high task-related effort as less effortful would require fewer cognitive resources to maintain the effort manipulation. In these individuals, cognitive resources are available for motor awareness and agency ascription. This account explains both the correlation between the effect of effort on binding and the subjective experience of effort, and also the effect of time-on-task in Experiment 1. Interestingly, this effect is not observed in task-unrelated physical effort. To explain this, it is considered that when under task-unrelated effort, the effort manipulation may have an indirect but strong effect on the efficiency of the mechanism by which agency is ascribed which leaves the individual experience of effort an unreliable source of agency. This effect could be due to the dual task demands of processing the effort manipulation with one effector, and the action with another (Experiment 2), which could be more demanding than processing input from a common source as in Experiment 1 (cf. Kahneman, 1973; Pashler, 1994).

Limitations and further research

This investigation into the role of effort on sense of agency was in part designed to complement the work of Demanet et al. (2013). However, the opposite pattern of results was found compared with their study. Demanet et al. found that high task-unrelated effort resulted in greater temporal binding compared with low effort with the explanation that the sensation of effort acts as a cue inferring self-agency resulting in greater temporal binding. Demanet et al. used the ‘Libet clock’ method whereas here the interval reproduction was used as an implicit measure of agency. It is possible that the differences in the pattern of results may be due to methodological differences. The interval reproduction method captures the temporal relationship between the action and consequence and reflects the slowing of an internal clock (Wenke & Haggard, 2009), whereas the ‘Libet clock’ method captures the temporal positioning of either the action or consequence, and not the relationship between those two events, so reflects shifts in event perception. This further means that although the action and the agency measure in both the current and Demanet et al.'s experiments are experienced concurrent to the effort manipulation there are key differences in the methodologies. The measure of agency in the current experiment is retrospective, experiential and longer lasting, and captured concurrent to the effort manipulation in the opposite effector (Experiment 2), or actually required physical effort (Experiment 1). Whereas, in Demanet et al. the temporal binding measure may be affected differently by the effort manipulation because it occurs concurrent to the reporting of the temporal positioning of an event on a visual clock face. Although, it is not completely clear how these two methods would produce divergent results, so it is important that future work pursues this empirical question. Finally, the current study did not asses hand dominance, individual levels of strength or the role of gender (the latter due to a small male sample). These issues could be further looked at in order to provide a similar level of relative physical exertion across effectors in investigations of task-related and unrelated physical effort, and to understand how effort affects temporal binding across differing strengths and across gender.

Conclusion

Experiments 1 and 2 investigated the influence of physical effort on temporal binding. It was found that the binding effect was reduced whilst under high effort in agentic conditions. It is concluded that effort generally and non-specifically affects implicit sense of agency, thought to be caused by depleted cognitive resources that would be otherwise dedicated to agency detection. When the effort is exerted by the same effector as that which is producing the environmental outcome, however, there is a more specific effect of effort whereby the individual's subjective experience of effort is taken into account. These results therefore further imply that a sense of agency is not necessarily generated in a uniform manner for any given action. Rather, the current state of the motor or cognitive system can disrupt a key mechanism that provides feedback about our actions in the environment. With regards to the role of physical effort as a cue for the generation of agency, the current findings indicate that rather than aiding the construction of agency, physical effort interferes with its generation through the diversion of critical cognitive resources necessary to produce the sense of agency.

Chapter 4: Mental effort disrupts implicit sense of agency

In everyday life humans act in the world whilst distracted, stressed and whilst multitasking. Under these conditions the perception of responsibility or authorship over our actions may alter. For instance, if whilst walking down the high-street with a cup of coffee in hand I am distracted by the sound of screeching and car horns beeping, I may feel less responsibility for bumping into a pedestrian and ruining their shirt with my coffee compared with if I was fully attending to my trajectory along the street. The outcome, a spilt drink on someone, is the same in both situations, however the action monitoring system which ascribes agency over the event interprets each situation with regards to the amount of attention available for my actions. In this chapter, the role of cognitive resource availability for the ascription of implicit agency is examined using a mentally effortful task.

As previously discussed, the availability of cognitive resources is an influential factor in the ability to create a sense of agency. When cognitive resources are limited due to the conscious processing of a primary task, fewer resources are available for the mechanism which ascribes agency. Agency is believed to be ascribed when there is a match between motor and sensory predictions and effects. The construction of the predictions rely on cognitive availability to monitor motor control and awareness. Therefore, when resources are diverted to a primary tasks, inaccurate motor and sensory predictions are created, causing a mismatch with the actual effects of action (Blakemore et al., 2001; Blakemore et al., 2002; Kannape et al., 2014; Lindenberger et al., 2000; Moore et al., 2009; Moore & Fletcher, 2012; Woollacott & Shumway-Cook, 2002).

Physical effort is known to tax the cognitive system (Block et al., 2016; Dietrich & Sparling, 2004; Féry et al., 1997). The cognitive resource limitation account for reduced agency under mentally taxing conditions is therefore lent support not only from the findings in Chapter 3, that physical effort reduces implicit sense of agency, but also from studies that directly and indirectly examine load on the cognitive systems. For instance, Hon et al. (2013) examined a direct manipulation of cognitive load for its role on explicit judgements of agency. Participants reported the degree to which they felt as though their action, a keypress on one of two arrow keys – upwards arrow or downwards arrow, caused an effect, a dot movement in the trajectory consistent or inconsistent with the direction of the arrow keypress. The delay between the keypress and dot moving was randomly selected from one of three delays: 100, 400 or 700ms. Participants were also under a concurrent working memory task. In this task participants were presented with a list of either six (high cognitive load) or two (low cognitive load) letters. At the end of the trial, after agency ratings, participants then recalled the letter in the list that followed the probe, i,e, if the probe was ‘X’, participants responded with the letter that occurred after ‘X’ in the list. The data revealed that in trials in which the dot moved in a consistent trajectory as the arrow keypress, the explicit ratings of agency were reduced under high cognitive load, compared with low cognitive load conditions. In trials where the dot moved in a direction inconsistent with the keypress, agency ratings were consistently lower, regardless of cognitive load. These data reveal that during successful conditions of agency, mental effort reduced explicit ratings of agency. It must be noted however, that the reduction in agency occurred only at the 100ms delay. This may reflect the sensitivities of explicit measures to contiguity suggested by the post-hoc inference account of agency (Minohara et al., 2016; Wegner, 2002; Wegner, 2003; Wegner & Wheatley, 1999). The authors proposed that the representation of action effect was impoverished by the cognitive burden of the high load. The effect after the 100ms delay was therefore likely to have occurred before accurate predictions of the effect could be made, resulting in mismatch between what was expected and the actual effect.

Other studies additionally offer indirect support as to the diminishing effect of mental effort on the sense of agency. Although, these studies do not address cognitive load directly. Instead cognitive conflict, which demands cognitive resources (see Greene et al., 2004), is manipulated in the form of either distractor stimuli causing action selection conflict, socially negative responses to actions, and action under coercion (Caspar et al., 2016; Sidarus & Haggard, 2016; Yoshie & Haggard, 2013). Under these conditions of cognitive conflict, implicit (Caspar et al., 2016; Yoshie & Haggard, 2013) and explicit (Sidarus & Haggard, 2016) agency is reduced. These data are believed to be broadly in line with and provide support for the resource limitation account for reduced agency under cognitive load that is proposed here. It is also important to note, however, that some other work indirectly investigating the effect of cognitive resources on temporal binding have found opposite effects. Haggard and Cole (2007) investigated the role of focused attention on temporal binding whereby attention was directed to either the key press action or to the consequent tone. They found that focused attention on one event resulted in a perceptual event shift which reflected stronger temporal binding. Barlas and Obhi (2013) further found that temporal binding was increased when the number of action choices was greater.

The effects found in which cognitive load (administered both directly and indirectly) reduced the sense of agency can be generally explained in terms of cognitive resource limitations. A result of ascertaining agency is the temporal binding of action to its effects (Wenke & Haggard, 2009), for which motor control and awareness are fundamental factors. During dual task performances cognitive resources are shared between the primary effort manipulation, such as working memory, or forms of cognitive conflict. Motor control and awareness are therefore disrupted, reducing agency. The degree of temporal binding is therefore also reduced. However, although the research by Hon et al. (2013) and Sidarus et al. (2016) addressed the role of cognitive load during the action over which agency was rated, both examined explicit judgements of agency. The work by Caspar et al. (2016) and Yoshie and Haggard (2011), examined implicit measures of agency, but these studies did not investigate mental effort directly, rather the motivation for the action and the consequence of the action was manipulated, respectively. Under some conditions, implicit and explicit measures of agency offer dissociable results (Dewey & Knoblich, 2014; Obhi & Hall; 2011). Therefore, investigating how mental effort directly influences agency using an implicit measure would be valuable in understanding the processes involved in agency attribution whilst under cognitive load. Such an investigation would also further clarify how implicit agency is constructed.

To provide evidence that can establish the role of mental effort for the construction of an implicit sense of agency, two experiments were conducted to examine the effects of cognitive load, operationalised using a working memory task, on interval reproductions of the action-outcome delay.

The experimental focus of Chapter 4

To determine the effects of mental effort on agency, a working memory tasks was employed simultaneous to the implicit measure of agency, interval preproduction. Working memory tasks are known to consume cognitive resources and so are considered a reliable manipulation with which to induce cognitive load and mental effort (Kahneman, 1973; Paas, Tuovinen, Tabbers & van Gerven, 2003; Pashler, 1994; Pashler & Johnston, 1998). Interval reproduction is also considered to be a reliable measure that indexes the implicit sense of agency (Buehner & Humphreys, 2009; Engbert et al., 2008; Humphreys & Buehner, 2010; Poonian & Cunnington, 2013). Experiment 3 induces mental effort using the Sternberg working memory task in which a first series of letters, two letters for low mental effort and six letters for high mental effort, must be retained in working memory during the agency measure. This is broardly similar to Hon et al. (2013). Note though that in Hon et al. agency was measured using an explicit measure. Experiment 4 further investigates the role of mental effort for the implicit sense of agency, however, the mental effort task from Experiment 3 is adapted such that the high mental effort condition contains eight letters, in order to make the cognitive load task more cognitively demanding.

Given the diminishing effects of both physical and mental effort on cognitive resources, and the influence of cognitive resource for agency ascription, it is predicted that high mental effort will not act as a cue aiding the generation of agency, but will rather result in a decrease in temporal binding in agentic conditions. The only study, that I am aware of, that directly measures the effect of mental effort meaured explicit ratings of agency but also found this effect (Hon et al., 2013). Experiment 2 also investigated task-unrelated physical effort, and found that high task-unrelated physical effort reduced implicit agency. Mental effort can also be considered as unrelated to the action, therefore it is predicted that the effect of mental effort, and the role of personalised task difficulty, will be similar to the effects observed in Experiment 2. Investigations in Experiments 3 and 4 aim to clarfiy if the diminishing effect of high mental effort for agency generalises to implicit measures of agency, and whether this effect is observed for task-unrelated mental effort.

Experiment 3: Mental effort

In Experiments 1 and 2 high physical effort reduced temporal binding. It is believed that these effects may be due to cognitive resource depletion as a result of physical strain which disrupted the mechanism by which agency was ascribed. Experiments 3 and 4 aim to examine the role of cognitive resource depletion more directly to clarify this effect. Mental exertion is unrelated to the execution of actions. Experiment 2 also studied action unrelated physical effort, so here it is explored whether the effect observed in Experiment 2 replicates under conditions of action unrelated mental effort. The cognitive system is depleted similarly under physical and mental effort, and the effect of effort appears to be not completely action-specific (see Experiment 2 whereby physical effort not task-related). Therefore, it is predicted that high mental effort tasks will result in reduced binding in agency conditions, compared with low mental effort, replicating Experiment 2.

In this experiment, participants were exposed to high and low levels of cognitive load, using a working memory task whereby items (2 or 6 for low and high effort levels, respectively) had to be kept in working memory during the stimulus interval and reproduction of this interval (adapted from Sternberg, 1966). If temporal binding is again found to be reduced under high (cognitive) effort, it would suggest that implicit sense of agency is vulnerable under conditions of effort, regardless of the source. This would mirror the data of Hon et al. (2013) who found these effects of cognitive load on agency using an explicit ratings task.

Method

Participants

Thirty-six participants (13 men; age range 18-22, *M* = 19.14 *SD* = 1.05) were recruited from the University of East Anglia and completed the experiment in return for payment or course credit. Participants gave informed consent and were naïve to the purpose of the experiment.

Apparatus and Stimuli

Experiment 3 examined the effect of cognitive load on temporal binding. To manipulate this, randomly selected letters (vowels and 'y' excluded, Arial font, font size 36, presented in white on a black background at encoding stage, and yellow font presented on a black background for probe letters) served as additional stimuli as part of the Sternberg (1966) memory task. Participants were tested in a group lab up to four participants at a time, but were separated in booths with no access to each other during the task. Stimuli were presented on a BenQ monitor (size: 24 inches; resolution: 1920 x 1080 refresh rate: 60 Hz) Auditory stimuli were presented using Sony 7506 headphones. The Adult Empathy Quotient (Baron-Cohen & Cartwright, 2004) was also administered at the end of the testing session as part of a pilot study for an unrelated research question and so is not discussed further.

Design

In a repeated measures design participants completed four experimental block types differing across two factors: Presence of Agency (Agency and No Agency) and cognitive load under the factor Mental Effort (Low and High). Sense of agency was measured, as in Experiments 1 and 2, as reproduction errors (calculated as the subtraction of stimulus intervals from response intervals). Reproduction Error Differential was calculated as in Experiments 1 and 2. During the Mental Effort manipulation, memory accuracy performance was recorded, from which an Accuracy Difference was calculated as accuracy score (percentage accurate) under Low Mental Effort minus accuracy score under High Mental Effort.

Procedure

Effort manipulation. Mental effort was manipulated using the Sternberg (1966) Memory task, adapted to administer Mental Effort under Low and High levels of cognitive load. The Memory task consisted of an encoding stage, a maintenance period, and a recall stage. During the encoding stage six randomly selected letters were presented successively for 1000 ms each. For Low and High Cognitive Load conditions two and eight letters, respectively, were presented at the encoding stage. The Interval Reproduction task served as the maintenance period, which was followed by the recall stage. The recall stage consisted of a probe letter to which participants distinguished whether or not (pressing '1' and '2', respectively) the probe was present at encoding, which was the case in 50% of trials (at random).

Presence of Agency manipulation. Agency was manipulated as in Experiments 1 and 2, using an Interval Reproduction task. The mean length of the jittered stimulus interval in the interval reproduction task was comparable in the four conditions across the Presence of Agency and Effort manipulations, Fs < 1.01, ps > .32. Before starting the experiment participants completed a short block practicing the Presence of Agency and Mental Effort manipulations. Each experimental condition contained 36 trials which were presented in two blocks of 18 trials each. Blocks were separated by a self-paced rest period. The order of block type was counterbalanced as in Experiments 1 and 2. At the end of each block participants were encouraged to take an unrestrained rest period. The full experiment lasted approximately 45 minutes. See Figure 10 for the experimental procedure across Mental Effort and Presence of Agency manipulations.

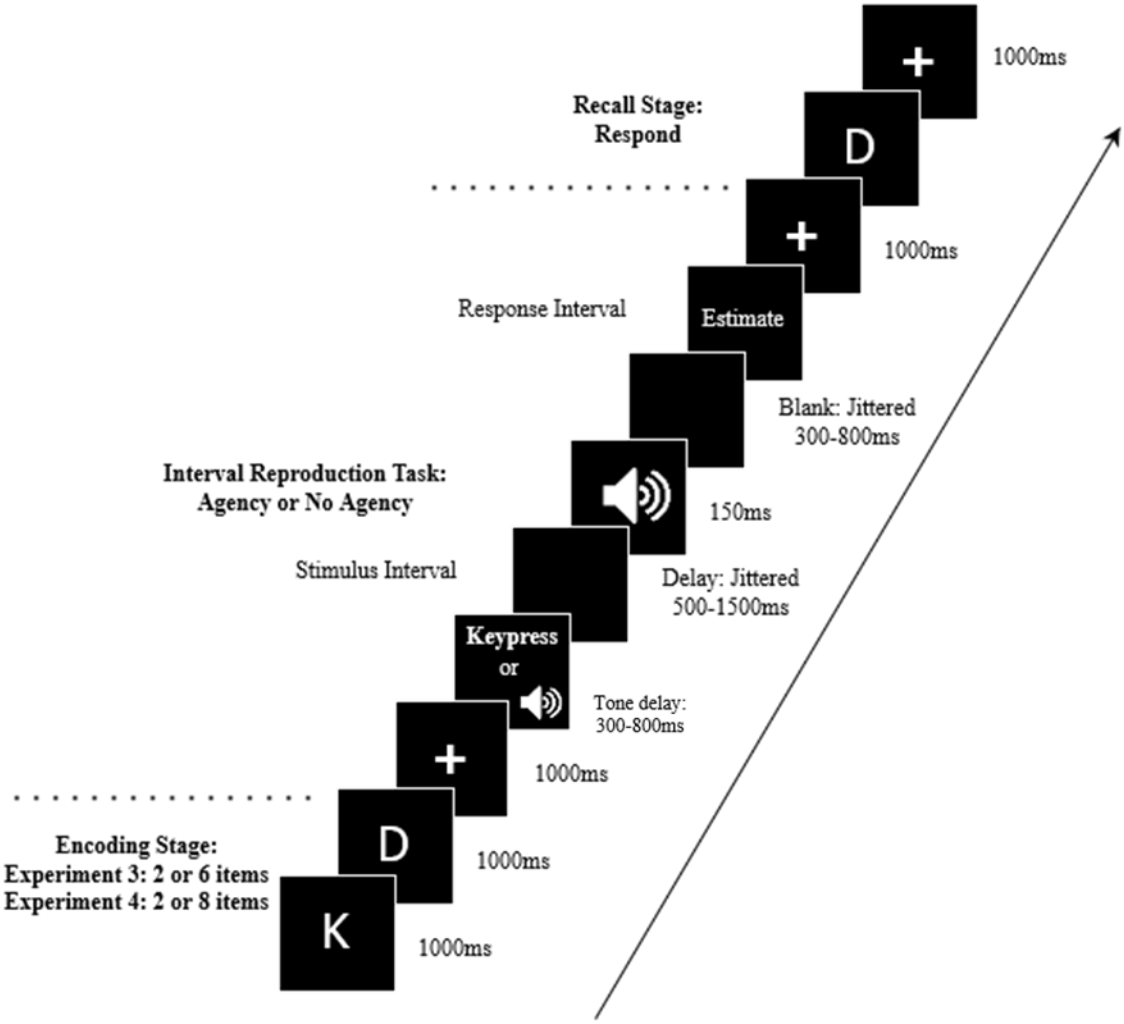

Figure 10. Procedure for Experiment 3 and 4: Participants were presented with a string of letters, two letters were presented in Low effort conditions, and six letter in High effort conditions in Experiment 3, in Experiment 4 eight letter were presented in High effort conditions. The Interval Reproduction task started after the string of letters. The first event consisted of either a spacebar press (Agency) or a tone (after a jittered delay of 300-800ms; No Agency). After a randomised stimulus interval (500-1500ms) the outcome, a tone, was presented. Participants were prompted to make response intervals by recreating the interval between the first event and outcome with the depression of the spacebar, after which the probe letter appeared, prompting participants to respond as to whether it had appeared at the encoding stage.

Cognitive Load Manipulation Check. Accuracy data percentages were analysed across the two factors (Presence of Agency and Mental Effort) using a 2 x 2 ANOVA. A main effect of Mental Effort was observed, F (1, 35) = 97.57, p < .001, ηp^2 = .74, because participants recalled more accurately under low compared to high load (*M* = 92%, *SD* = 10.01, and *M* = 80%, *SD* = 9.24). Neither main effect of Presence of Agency, nor the interaction between the two factors were significant, *F*'s<1.

Results

Trials with extreme reproduction errors (>3*SD* from the individual's mean) were removed (0.46% of trials), as were trials in which responses in the recall stage were inaccurate (13.23%).

Mean reproduction errors for each participant in each condition were submitted to a 2 (Presence of Agency) X 2 (Mental Effort) ANOVA, which revealed a significant main effect of Presence of Agency, F (1, 35) = 31.0, $p < .001$, $\eta p^2 = .47$, because reproduction errors were greater in conditions of Agency compared to No Agency (*M* = -207.17ms, *SD* = 277.68, and *M* = -18.42ms, *SD* = 371.96, respectively). A main effect of Mental Effort was not observed, F (1, 35) = .098, p =.76, $\eta p^2 = .003$. But the interaction was significant, F (1, 35) = 5.0, p = .03, $\eta p^2 = .13$. Planned contrasts (Figure 11) examined the interaction revealing non-significant differences in reproduction error across Low and High effort for Agency; (Low: *M* = -220.62ms, *SD* = 290.82; High: *M* = -193.72ms, *SD* = 273.17) and No Agency (Low: *M* = -9.38ms, *SD* = 361.02; High: *M* = -27.46ms, *SD* = 390.06) tasks, t (35) = 1.62, p = .12, $d_z = .27$ and t (35) = 1.01, p = .32, $d_z = .17$, respectively. This is interpreted as limited evidence for reduced implicit agency under cognitive load, and this led to the motivation to test a higher load level (8) for High mental effort, presented as Experiment 4.

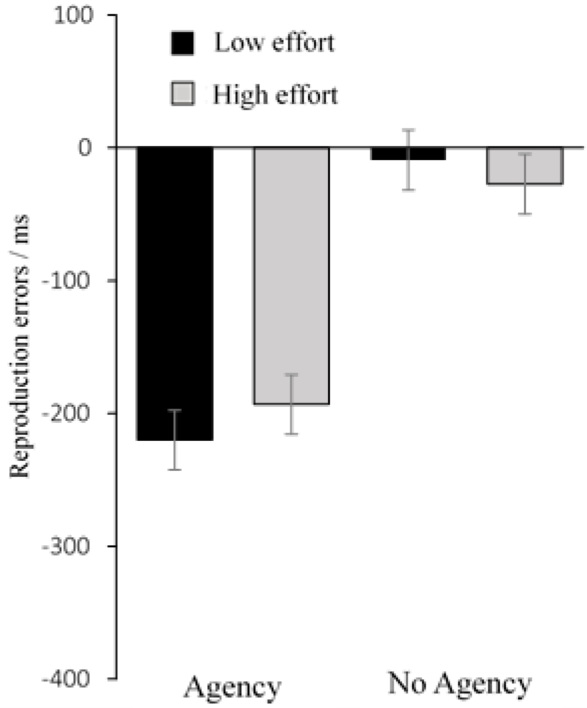

Figure 11. Mean reproduction errors across factors Presence of Agency and Effort for Experiment 3. Bars extending below the x-axis reflect an underestimation of the stimulus interval (temporal binding).

In this experiment, participants were not asked to provide ratings of how much effort they exerted under high and low effort. Instead, the objective measure of their performance acts as a proxy for effort. That is, an individual's difference in accuracy between the high and low cognitive load conditions can be used as an index of how much more taxing the high load task was relative to the low, for each individual. Like before, this was correlated with the difference in the effect of agency between the high and low effort conditions (see Figure 12). The correlation was not significant, $r(34) = -.069$, $p = .691$, and was significantly weaker than the significant positive correlation from Experiment 1 ($z = 2.62$, $p = .009$). This relationship was also not significant if only considering the mean accuracy scores for the High and Low conditions, $r(34) = -.103$, $p = .55$ and $r(34) = -.043$, $p = .8$, respectively. As in Experiments 1 and 2, the performance on the first and second halves of the experiment were compared with the factor 'Time on

Task'. The three-way interaction was non-significant, $F(1, 35) = 1.72$, meaning that the effect of mental effort on agency was stable across the experiment session.

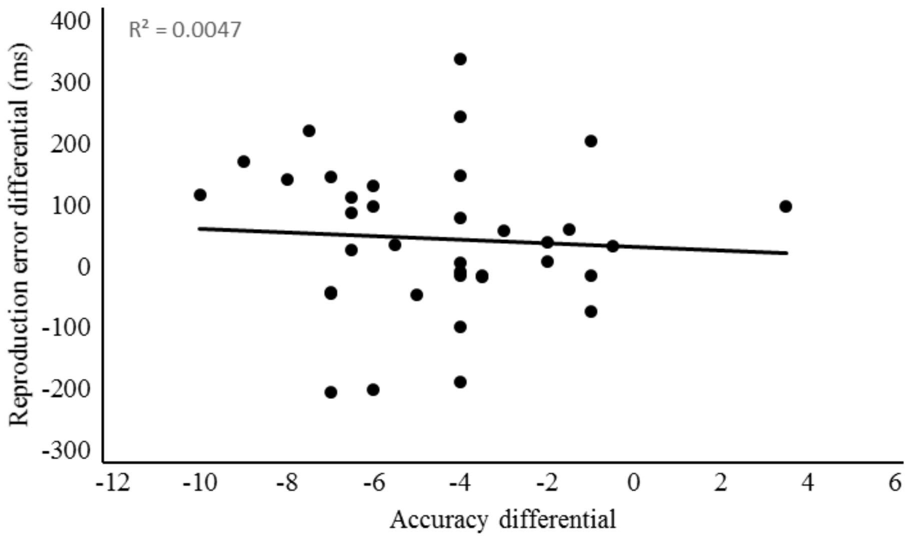

Figure 12. The non-significant relationship between Accuracy Differential and Reproduction Error Differential.

Discussion

Overall, the data in Experiment 3 indicate agency effects whereby there was greater temporal binding during conditions in which agency was present. This replicates previous work and Experiments 1 and 2 (Buehner & Humphreys, 2009; Engbert & Wohlschläger, 2007; Engbert et al., 2007; Haggard et al., 2002; Humphreys & Buehner, 2010). The critical interaction although was significant did not produce reliable contrast effects when comparing across effort levels and agency manipulations. However, there was a trend whereby in Agency tasks reproduction errors were reduced under high load compared to low load. The trend in the data therefore accord with findings that cognitive load reduces agency (Hon et al., 2013). This is therefore interpreted as limited evidence for cognitive load reducing implicit agency, and led to a subsequent study (Experiment 4) in which the mental effort manipulation for high effort was more demanding on the cognitive resource system.

Hon et al. (2013) employed a working memory task that was arguably more cognitively demaning that the task employed here. In their study participants were presented with the letter at encoding stage together on one screen. At the recall stage participants then responded as to the letter which *followed* the probe letter. This may have required more cognitive resources than simply identfying whether a probe letter was present, as in Experiment 3. This may account for the data failing to demonstrate reliable effects of effort across agency manipulations (whereby the critical interaction was significant but the critical contrasts were not significance). The subsequent Experiment 4, therefore increases the number of letters present at encoding to eight letters in order to more greatly burden the cognitive system.

Experiment 4: mental effort replication with increased cognitive load

Experiment 3 aimed to investigate the effects of mental effort on the implicit sense of agency, predicting that high effort would result in a reduction of temporal binding, the pattern of results observed for task-related and task-unrelated physical effort (Experiments 1 and 2). Experiment 3 offered only limited support for these predictions. It is believed that limitations in cognitive resources are responsible for the reduction in implicit sense of agency, so it is possible that the cognitive load task used in Experiment 3 was not resource consuming enough to interfere with agency attributions. Therefore, in order to establish whether cognitive load reduces implicit sense of agency a follow up experiment was conducted in which the mental effort manipulation further drew from the cognitive resource pool. In this subsequent experiment (Experiment 4), the high load mental effort manipulation consisted of eight items to retain in working memory.

Method

Participants

Thirty-six participants (6 men; age range 18-29, $M = 20.39$ $SD = 2.05$) recruited from the University of East Anglia, completed the experiment in return for payment or course credit. Participants gave informed consent and were naïve as to the purpose of the experiment.

Apparatus, Design and Procedure

The only alteration compared with Experiment 3 was that the number of letters presented at encoding stage of the memory task at High load was eight (see Figure 10). The mean length of the jittered stimulus interval was comparable in the four conditions across the Presence of Agency and Effort manipulations, Fs < 2.1, ps > .12.

Cognitive Load Manipulation Check. Accuracy data percentages were analysed across the Presence of Agency and Mental Effort factors using a 2 x 2 ANOVA. A main effect of Mental Effort was found, $F(1, 33) = 176.06$, $p < .001$, $\eta p^2 = .84$, because participants recalled more accurately under low compared to high load (M = 92%, SD =

5.9, and *M* = 72%, *SD* = 7.4). Neither main effect of Presence of Agency, nor the interaction between the two factors were significant, *F*'s<1.

Results

Data from one participant were removed because they did not respond to the probe letter the working memory task. Trials with extreme reproduction errors were removed (0.54% of trials), as were trials in which responses in the recall stage were inaccurate (17.5%). One additional participant produced extreme interval reproduction scores and therefore was not submitted to further analysis. The sample size included for data analysis was therefore N = 34.

Mean reproduction errors for each participant in each condition were submitted to a 2 (Presence of Agency) X 2 (Mental Effort) ANOVA, which revealed a significant main effect of Presence of Agency, $F(1, 33) = 69.74$, $p < .001$, $\eta p^2 = .68$), whereby Agency tasks had greater reproduction errors than No Agency tasks (*M* = -215ms, *SD* = 253 and *M* = -22ms, *SD* = 323ms, respectively). There was no main effect of Mental Effort, $F(1, 33) < 1$, but the interaction was significant, $F(1, 33) = 4.56$, $p = .04$, $\eta p^2 = .12$.

Planned contrasts examined the interaction revealing that for No Agency tasks there was no effect of effort, $t(33) = .88$, $p = .39$, $d_z = 0.149$**.** However, for Agency tasks an effect of Mental Effort was observed, $t(33) = 2.1$, $p = .044$, $d_z = 0.36$, whereby reproduction errors were greater under Low effort (see Figure 13).

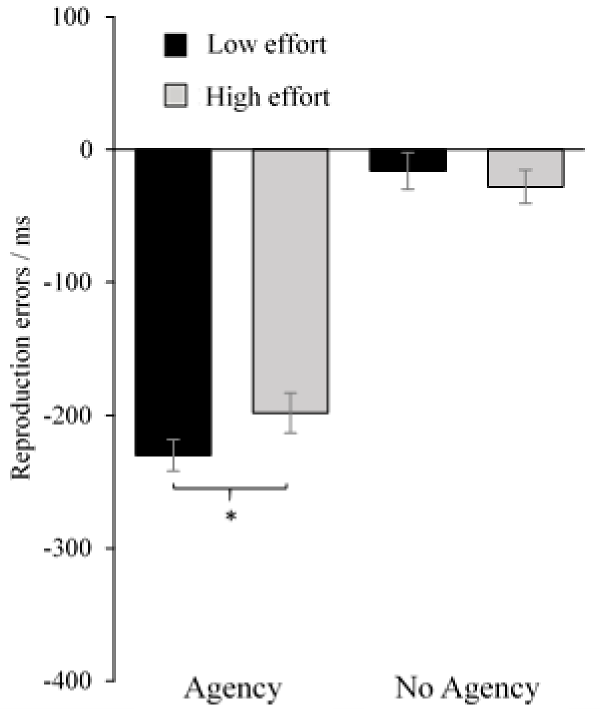

Figure 13. Mean reproduction errors across factors Presence of Agency and Effort for Experiment 4. Bars extending below the x-axis reflect temporal binding.

Like in Experiment 3 individual's difference in accuracy between high and low load conditions was correlated with the difference in the effect of agency between the high and low effort conditions (see Figure 14). As in Experiment 3, the correlation was not significant, $r(32) = -.113$, $p = .523$, and was significantly weaker than the significant positive correlation from Experiment 1 ($z = 2.73$, $p = .006$). Again, like in Experiment 3 this relationship was not significant if only considering the mean accuracy scores for the High and Low conditions, $r(32) = -.149$, $p = .402$ and $r(32) = -.018$, $p = .92$, respectively. As in Experiments 1 and 2, the performance on the first and second halves of the experiment were compared with the factor 'Time on Task'. The three-way interaction was non-significant, $F(1, 33) < 1$, meaning that the effect of effort on agency was consistent across the experiment session.

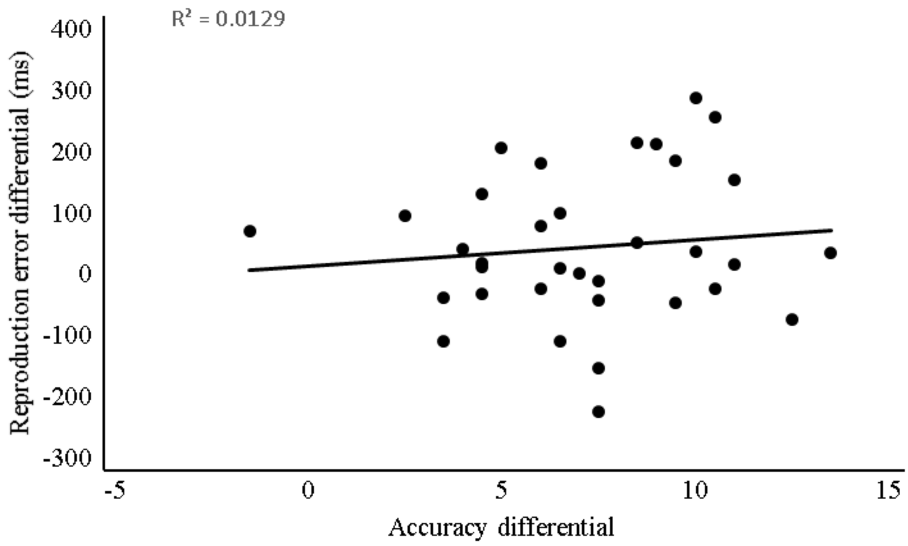

Figure 14. The non-significant relationship between Accuracy Differential and Reproduction Error Differential.

Discussion

Experiment 4 aimed to determine effort effects in action-unrelated cognitive load on temporal binding. In addition to the basic temporal binding effect under conditions of agency, an interaction with effort was also observed. In conditions in which agency was present, high mental effort decreased temporal binding compared with low mental effort conditions. This effect of mental effort was not observed in conditions in which agency was absent. These effects on temporal binding therefore reflect those found for both action-related and –unrelated physical effort (Experiments 1 and 2, respectively). Here there was no modulatory role of the individual experience of effort, or of time on task, on the effect of effort on temporal binding. This reflects the findings for Experiment 2, task-unrelated physical effort. Taken together, the data collected in Experiments 3 and 4 using the cognitive load task shows that mental effort reduces temporal binding under conditions of agency, which is in line with that observed using explicit measures (Hon et al., 2013).

General discussion

Experiment 3 and 4 investigated the effects of mental effort on implicit sense of agency. An interval estimation paradigm was used and temporal binding effects were in line with previous studies, whereby during conditions of agency temporal binding is increased compared with conditions absent of agency (Buehner & Humphreys, 2009; Pooninan & Cunnington, 2013). Of particular interest here was the role of mental effort, and whether mental effort would modulate the temporal binding effect observed across agency conditions.

The data revealed that under conditions of agency temporal binding was weaker under high mental effort compared with low mental effort. This effect was not found for conditions absent of agency. Statistical effect sizes for the critical interactions were small (Experiment 3 $\eta_p^2 = .13$; Experiment 4 $\eta_p^2 = .12$), and the effects sizes for the key contrasts in Experiment 4 were small to medium ($d_z = .36$; note the key contrasts were non-significant in Experiment 3).

Potential mechanisms for reduced sense of agency under mental effort

In Experiments 3 and 4 high mental effort was found to reduce implicit sense of agency (however, note that in Experiment 3 although the critical interaction was significant and the pattern of data followed expected trends, the contrasts were non-significant). The cognitive load task used to manipulate levels of low and high mental effort directly consumed cognitive resources. Theories of agency ascription suggest that the sense of agency arises from congruence between sensory and motor predictions and actual sensory and motor effects (Blakemore et al., 2001; 2002). This process is believed to require cognitive resources (Huxhold et al., 2006; Kannape et al., 2014; Lacour et al., 2008; Lindenberger et al., 2000; Woollacott & Shumway-Cook, 2002). When undertaking a highly cognitively demanding task, such as the high effort working memory task employed here, it is likely that cognitive resources are depleted and fewer resources are available to make accurate sensory and motor predictions with which to compare with sensory and motor effects. In instances of reduced cognitive resources availability for agency attribution is reduced. This finding is observed because temporal binding reduced under high effort in agency conditions, and supports the findings by Hon et al. (2013) whereby cognitive load decreased explicit ratings of agency. The resource limitation account for reduced agency is also indirectly supported by studies which induce cognitive conflict (Caspar et al., 2016; Yoshie & Haggard, 2013).

As in Experiment 2, Experiments 3 and 4 showed no effects of personalised task difficulty. Rather, mental effort had a general effect on reducing temporal binding regardless of accuracy. A potential reason for this is due to limited cognitive resources with which to assess the reliability of the cue. It is believed that the availability of cognitive resources is limited under the high effort manipulations because the effort task was unrelated to the action. This may have resulted in dual task demands on the cognitive resource system. In this instance the effort manipulation would consume cognitive resources, depleting resource availability for processing agency attributions.

Limitations and further research

Although the pattern of data in Experiment 3 and 4 indicate that implicit sense of agency is reduced under high mental effort other work has indirectly investigated the role of cognitive resources on temporal binding as a measure for an implicit sense of agency, finding opposite effects. Haggard and Cole (2007) investigated the role of focused attention on temporal binding. In the study participants' attention was directed to one of two events, either towards the key press action or - in other trials - to the consequent tone. They found that focused attention on one event resulted in a perceptual event shift in a manner reflecting temporal binding that was stronger for the attended event. Another study that indirectly manipulated cognitive load also found increased temporal binding when the number of action choices was greater (Barlas & Obhi, 2013). The key differences between these two studies and the current studies are that here mental effort exerted during the task was directly manipulated, and moreover, the mental effort manipulation was unrelated to the relevant action, whereas Haggard and Cole directed mental effort to different aspects of the task itself, and Barlas and Obhi manipulated the difficulty of the task. Both these papers showed the opposite of what was found here. However, it is also noted that Hon et al. (2013) showed that explicit agency is reduced – like the present finding with implicit agency – using a similarly non-task-focused manipulation of mental effort. It is therefore likely that the effect of mental effort on agency may critically depend on the source of the cognitive load.

The use of the working memory load task in the current study may have introduced additional variables that were not accounted for. For instance, in the high load task participants' performance dropped below that of the performance in the low load task. This drop in performance may indicate that the participants were not able to carry out the task, or that they were not carrying out the task in the same way as in successful trials. To overcome this issue, the mental effort manipulation would perform such that participants can complete the task comparably well across the high and low load conditions. Methodological changes may therefore include presenting all letters at the same time, rather than consecutively.

Whilst the low cognitive load condition allows comparisons in temporal binding to be made across low and high levels of mental effort, it is also important to consider the effect that the load task may have had on the agency measure. The expenditure of a small amount of cognitive resources on a low load task may have resulted in changes to temporal binding which could not be detected by the current experimental design. Future research may therefore include a baseline control condition in which there is no mental effort task to determine if this is the case.

The current study focused on the role of cognitive load on the implicit measure of the sense of agency. In order to more fully understand how agency is ascribed under such conditions it would be important to examine the role of other types of cognitive burden. At the same time, investigations can examine limited cognitive resources in a more naturalistic context, such as when experiencing stress or fatigue, for example. Investigating agency under cognitive burden for outcomes with real-world importance or self-relevance will also further our understanding of how and whether agency is influenced across a range of contexts which have better relevance and real-world implications.

Real world applications to reduced agency under physical and mental effort

Everyday life consists of effortful actions, fatigue, strain, stress and multitasking. The current study suggests that individuals under these conditions may feel an impaired sense of agency for their actions. This could have implications for moral decision making and responsibility, especially in environments in which cognitive resources are challenged (Caspar et al., 2016). For instance, the feeling of responsibility for actions that lead to accidents may reduce under conditions of fatigue and stress. Indeed, this could be one mechanism by which the action monitoring system itself fails to provide adequate action control under fatigue/stress, leading to erroneous or negligent acts. This notion could have further implications for how the law manages responsibility for actions in the context of mental and physical fatigue.

Conclusion

Experiments 3 and 4 investigated the influence of mental effort on temporal binding to determine directly, the role of cognitive resource depletion on agency ascription. It was found that the binding effect was reduced whilst under high effort in agentic conditions. Comparably for the role of physical effort observed in Chapter 3, mental effort is believed to generally affect implicit sense of agency through cognitive resource depletion that would be otherwise be used to ascribe self-agency. These results therefore lend further support for the notion that the current state of the motor or cognitive system can disrupt a key mechanism that provides feedback about our actions in the environment. This has implications regarding stress, fatigue and divided attention that is faced in everyday life, and how responsibility under such circumstances may be managed in law. Furthermore, this indicates that, like physical effort, despite at face value presenting as a cue that one is an agent in the world, mental effort does not act as a cue and aid the generation of agency. Rather, mental effort hinders the construction of agency by reducing the cognitive resource availability necessary for agency construction.

Chapter 5: Neural correlates of agency

Consider an orchestra, with numerous musicians creating a vast array of notes and sounds. The ability to play an instrument in such contexts relies on the musicians' ability to distinguish which sounds are a result of their own actions and which sounds are generated by other musicians. This ability is directly related to the sense of agency since without the capacity to identify the outcomes generated by the self, there would be no event to experience agency over. One mechanism which facilitates this detection of self-generated sensory events is sensory attenuation.

Sensory attenuation refers to the reduction in the processing of self-generated events. This phenomenon is believed to function through motor prediction forward models whereby expected effects of actions are predicted through efference copies which allow the prediction of motor states and sensory consequences of the action (Blakemore et al., 2001; David et al., 2008; Davidson & Wolpert, 2005; Synofzik et al., 2008; Wolpert et al., 1995; Wolpert, 1997; Wolpert & Ghahramani, 2000). The reduction in processing of self-initiated events has been shown by the reduction of salience of stimuli across a range of sensory domains compared to when they are externally generated. For instance, self-generated tones are experienced as quieter than computer or other generated tones (Weiss et al., 2011). The sensation of tickling is lessened for self-tickling compared to other-initiated tickling (Bays et al., 2006; Blakemore et al., 1998; Blakemore et al., 1999; Blakemore, et al., 2000). The detection of expected action-effects are also found to be impaired following self-generated key presses (Cardoso-Leite, Mamassian, Schütz-Bosbach & Waszak, 2010), and changes to stimuli are less well detected when the changes are a result of own actions (Berberian & Cleeremans, 2010).

As introduced in Chapter 2, sensory attenuation is also confirmed neurally, whereby the amplitude of the waveforms comprising the auditory N1 and P2 ERPs, which reflect the processing of auditory stimuli, are reduced during conditions in which agency is present, for instance, for speech and tones that are self-generated (Ford et al., 2007; Ford et al., 2013; Horváth et al., 2012; Knolle et al., 2012; Knolle et al., 2013; Kuhn et al., 2014; Martikainen et al., 2005; Poonian et al., 2015; Sowman et al., 2012; Timm et al., 2014). However, the P2 has also been reported to be unaffected by self-agency, in which no attenuation is observed for self-initiated tones (Bäß, Jacobsen & Schroger, 2008; Martikainen et al., 2005; Poonian et al., 2015). An interesting effect is also found for observed agency. Poonian et al. (2015) instructed participants to either make a keypress action which caused a tone, or to observe a video of another human agent making the keypress action. It was found that the N1 response to the tone was attenuated for agency conditions, regardless of whether the action was carried out by the self or not. Moreover, the degree of temporal binding was also comparable across acted and observed agency conditions. These data indicate that N1 is sensitive to agency due to the expectation of the outcome when preceded by an action which predictably causes such an outcome. N1 suppression is therefore not directly dependent on forward motor prediction. Other instances of N1 suppression to events is for repeated stimuli (Grill-Spector et al., 2006).

In addition to the neural and perceptual attenuation of events that occur as a result of self-generation, research has also revealed that the pre-supplementary motor area (pre-SMA), the part of the brain responsible for the planning of motor acts, contributes to the generation of agency. This is because the neural planning of motor acts provides a blueprint for the expected efference copies, which, in accordance with the forward models of motor control, are important for determining self-agency (Blakemore et al., 2001; 2002). Indeed, Moore et al. (2010) found that disturbance of the pre-SMA using transcranial magnetic stimulation (TMS) resulted in reduced temporal binding between the action and outcome. Moreover, Jo et al. (2014) investigated the readiness potential, which is action preceding cortical negativity believed to capture the preparation and planning of motor acts in the Pre-SMA (Libet et al.,1983; Shibasaki & Hallett, 2006). They found that the amplitude of the early readiness potential, but not the late readiness potential, correlated with the degree of temporal binding, whereby the outcome shifted towards the action. It must be noted however, that the degree of temporal binding is not directly indexed by the readiness potential. Poonian et al. (2015) found that although temporal binding was present both for observing and enacting agency conditions (whereby a keypress caused a tone), the readiness potential was only observed when the participants carried out the action, and not when they observed an action.

The effect of cognitive load on perceptual and neural attenuation

Sensory attenuation is a phenomenon that occurs dependent on the availability of cognitive resources. Its function is to act as a mechanism with which to save cognitive resources for the processing of unexpected stimuli which may necessitate attention and fast reaction to (Bays et al., 2006; Hess et al., 2009). However, sensory attenuation can be reduced or induced depending on the degree of cognitive resource availability to the stimuli (Boksem et al., 2005; Hillyard, Hink, Schwent & Picton, 1973, Horváth & Winkler, 2010).

A number of studies have investigated the role of cognitive load for its effects on the perceptual salience of other stimuli. For instance, increased difficulty of a visual search task resulted in reduced detection sensitivity of auditory tones and speech (Macdonald & Lavie, 2011; Mattys & Wiget, 2011; Molloy, Griffiths, Chait & Lavie, 2015). These effects of reduced perceptual detection as a function of cognitive load are also observed neurally. For instance, using magnetoencephalography to detect differences in brain activity, reductions in early (~100ms) auditory evoked activity to tones were found when attention was divided using a visual perceptual load task (Molloy et al., 2015). The amplitude of the auditory N1 has also been shown to be enhanced when attention to the particular stimuli is increased (Hillyard et al., 1973, Horvath & Winkler, 2010). Whereas, decreased attention to stimuli induced by mental fatigue reduced the N1 amplitude to visual stimuli (Boksem et al., 2005). Caspar et al. (2016) also provide indirect support for N1 attenuation as a function of reduced cognitive resources, showing that tones caused by actions under coercion result in attenuated N1 responses to the tone. Although this study addresses coercion and not cognitive load directly, coercion can be considered a form of cognitive conflict, which demands cognitive resources (see Greene et al., 2004). Currently, to my knowledge, there is no evidence to suggest that P2 is influenced by the availability of cognitive resources.

Pre-movement neural activity is also found to be influenced by the levels of cognitive resources directed towards the action. For instance, when participants were instructed to attend to the intention to move, rather than the action itself, pre-SMA activity was found to increase, as measured using functional magnetic resonance imaging (Lau, Rogers, Haggard & Passingham, 2004). The readiness potential has been further indicated to be influenced by cognitive load (Baker, Mattingley, Chambers & Cunnington, 2011). Participants were instructed to make voluntary self-paced finger movements and concurrently take part in high or low cognitive load tasks. Participants were asked to either respond to when a letter in the stream of letters matched one that had appeared two displays beforehand (high load), or to respond to the appearance of a probe letter (low load). The results showed that the readiness potential was significantly attenuated under conditions of high cognitive load. The planning of movement is believed to require cognitive resources to focus on the moment at which to execute the action. The effect of attenuated readiness potential under high cognitive load therefore occurs due to the disruption to the planning of movement initiation (Baker et al., 2011). The role of cognitive load tasks on the readiness potential in Baker et al. was not considered in the context of agency, however, it can be expected that if the readiness potential influences the degree of conscious intention to act and provides a blueprint of efference copies, then a reduction in the readiness potential may disrupt the degree of temporal binding over the action caused outcome. To my knowledge this investigation has not yet been considered directly. However, Jo et al. (2014) indirectly examined the role of attentional control and self-regulation on the readiness potential and temporal binding. In this study attentional control was operationalised through the recruitment of experienced meditators for their ability to keep a strong focus of attention. Nevertheless, no effect of meditation on the readiness potential or the degree of temporal binding was observed.

The experimental focus of Chapter 5

Chapter 4 identifies that rather than acting as a cue aiding the generation of agency, cognitive load deters it. In particular, reduced resource availability weakens the implicit measure of agency, whereby under conditions of agency, as cognitive load increases temporal binding reduces. The literature outlined above further demonstrates that the N1 component is sensitive to conditions of agency. Moreover, the readiness potential and the N1 component are sensitive to increased cognitive load, such that the waveform amplitudes are smaller, reflecting attenuated planning of voluntary actions, and attenuated sensory processing of stimuli, respectively. Despite this, currently little is understood regarding the role of cognitive load for neural mechanisms in agency. The modulatory role of cognitive load on the readiness potential and N1/P2 complex is therefore investigated for its impact on the sense of agency.

The relationship between the topics of cognitive load, the readiness potential, N1, P2 and the sense of agency, to my knowledge, has not yet been directly investigated together. Here, to manipulate mental effort the Sternberg working memory task was employed as in Experiment 4, whereby participants are required to keep in working memory a list of either 2 (low load) or 8 (high load) letters. Also, the sense of agency is measured using the interval reproduction method of temporal binding. The current study therefore possesses several similarities to previous research. For instance, regarding the investigation of cognitive load, although the working memory tasks are different, this experiment maps closely with Baker et al. (2011) who also manipulated working memory, but unlike the current experiment, Baker et al. used an n-back style task to examine the role of cognitive load on readiness potential. This experiment however, neither examined the effect of cognitive load on the N1/P2 complex, nor on the sense of agency. Caspar et al. (2016) investigated, what is believed to be an indirect form of cognitive load, coercion, with regards to its effects on N1 and the sense of agency. The current experiment again is therefore somewhat similar to Caspar et al., with the exception that Experiment 5 directly manipulates cognitive load, and here the interval reproduction method is used, whereas Caspar et al. used the Libet clock method of temporal binding. Poonian et al. (2015) investigated the role of agency on the readiness potential and the N1/P2 complex using an interval reproduction method. The current experiment is therefore similar to this study with the exception that Poonian et al. examined the influence of acted and observed agency, whereas Experiment 5 novelly investigates the role of mental effort for agency and its effects on the readiness potential and N1/P2 complex.

Chapter 4 indicates that cognitive load weakens the implicit measure of the sense of agency. It is believed that depleted cognitive resources result in inaccurate comparisons to be made regarding predicted and actual motor and sensory effects of action. This would result in reduced expectation of the sensory effect, to which the N1 amplitude would remain stable. Previous research, however, indicates that limited cognitive resource are found to attenuate N1 responses, reflecting the reduced processing of the sensory outcome. Limited cognitive resources further result in an attenuated readiness potential, which may reflect reduced awareness of the intention to act. It is therefore clear that there is an interesting relationship between cognitive load, the sense of agency and neural indicators of agency. The current experiment therefore examines the modulatory role of mental effort on the readiness potential and N1/P2 complex, and how this impacts the implicit temporal binding measure of sense of agency.

Experiment 5

Experiment 5 aims to build on the findings of Experiments 3 and 4 which examined the effects of mental effort on the sense of agency. Specifically, in Experiment 5, the neural markers for the sense of agency are investigated. Participants took part in a temporal binding paradigm whilst under varying levels of mental effort (as in Experiments 3 and 4). It is predicted that mental effort will deplete cognitive resources which are necessary for generating an agency signal. Therefore, it is expected that temporal binding will be reduced under high cognitive load during agency conditions. It is further predicted that the N1 and P2 components will be attenuated for tones following an action, and for repeated tones. The neural markers of the sense of agency are expected to be modulated by agency and load manipulations. If cognitive load interrupts action planning, then the amplitude of the readiness potential will be greater under agency conditions, but weakened by high cognitive load. If cognitive load weakens the generation of the sense of agency, then N1 amplitude to sensory consequences of actions will be greater under high load, because the expectation of action effects is not processed. On the other hand, it has been found that cognitive load results in attenuated N1 responses, so what we may observe is that N1 is weakened under high cognitive load because resources are diverted to the primary cognitive load task.

Method

Participants

Thirty-eight female participants aged 18-39 (*M* = 22.47 years, *SD* = 8.25) were recruited from the University of East Anglia. Participants were naïve as to the research question, completed the experiment in return for course credit or payment, and gave informed consent. The study was approved by the School of Psychology Research Ethics Committee, University of East Anglia.

Materials

Participants completed three scales measuring schizotypy: Schizotypal Personality Questionnaire – Brief (SPQ-B; Raine & Benishay, 1995; Appendix 2), Cardiff Anomalous Perceptions Scale (CAPS; Bell, Halligan & Ellis, 2006**;** Appendix 3), and Mason's Short Scales for Measuring Schizotypy (SMSS; Mason, Linney & Claridge., 2005; Appendix 4), and a scale assessing negative emotional states of depression, anxiety, and stress: Depression Anxiety Stress Scales (DASS; Lovibond & Lovibond, 1995; Appendix 5). The scales were presented using Qualtrics survey software. During data analysis it was evident that there was no modulating role of levels of schizotypy, depression anxiety or stress so these measures are not further discussed. Instead, Chapter 6 investigates the role of individual differences in schizotypy further, where further details of the scales can be found.

Stimuli and apparatus

Mental effort manipulation. Mental effort was manipulated as in Experiment 4, using the Sternberg (1966) memory task. Randomly selected letters (vowels and 'y' omitted, Arial font, font size 36) were presented in white on a black background during the encoding stage, and in yellow font on a black background for probe letters. Stimuli were presented on a BenQ monitor (size: 24 inches; resolution: 1920 x 1080 refresh rate: 60 Hz) and auditory stimuli (a 150ms tone created using Audacity® software) were presented using Logitech speakers.

Design

In a 2 x 2 repeated measures design participants completed four experimental block types across two factors: Presence of Agency (Agency and No Agency) and Mental Effort (Low and High). The dependent measures were the reproduction error, measured as the stimulus interval minus the response interval (ms); accuracy in correctly identifying the presence of the probe letter in the letter stimulus list at encoding stage across the Mental Effort manipulations; and preaction potentials and auditory ERP components calculated from the EEG data. As in Experiments 3 and 4 Reproduction Error Differential was also calculated as the difference in reproduction errors between Agency and No Agency conditions under High vs. Low effort conditions ([Agency High – No Agency High] – [Agency Low – No Agency Low]). A positive Reproduction Error Differential score indicates a difference in reproduction errors across low and high effort in Agency conditions, whereas a negative Reproduction Error Differential score indicates this effect in No Agency conditions. Amplitude Differential scores were also calculated as the difference in amplitude between Agency and No Agency conditions under High vs. Low effort conditions ([Agency High – No Agency High] – [Agency Low – No Agency Low]). A positive Amplitude Differential score indicates that the degree of difference in amplitude across low and high effort is greater in Agency conditions, whereas a negative Amplitude Differential score indicates this effect in No Agency conditions. Amplitude Differentials were calculated for -100ms time intervals of the readiness potential, N1 and P2. As in Experiments 3 and 4, during the Mental Effort manipulation memory accuracy performance was recorded, and an Accuracy Difference was calculated as Accuracy Low effort – Accuracy High effort.

Procedure

The scales were administered as one questionnaire prior to the lab session and were in the order: SPQ-B, SMSS, CAPS, DASS. Completion of the questionnaire took approximately 15 minutes. Mental effort and the Presence of Agency manipulations were administered as in Experiments 3 and 4, with the same number of trials (36) per condition. The mean length of the jittered stimulus interval was comparable in the four conditions across the Presence of Agency and Effort manipulations, Fs < 1.66, ps > .21.

Mental effort manipulation check. Accuracy data percentages were analysed across Presence of Agency and Mental Effort manipulation factors using a 2 x 2 ANOVA, indicating that the effort manipulation was successful. A main effect of Mental

Effort was observed, $F(1, 34) = 244.39$, $p < .001$, $\eta p^2 = .878$, because participants recalled more accurately under low compared to high load (M = 92%, SD = 5.46, and M = 72%, SD = 7.64). The main effect of Presence of Agency, and the interaction were non-significant, F's<1.

EEG acquisition.

EEG recording. EEG was recorded using a 63-channel active electrode system (Brain Products GmbH: BrainVision actiCAP) embedded in a nylon cap, placed according to the extended international 10-10 system. Data were sampled at a rate of 500 Hz with FCz as the reference. EOG recordings were monitored using the electrode taken from the electrode site O2, and was positioned diagonally below and away from the outer canthus of the left eye. Impedance below 20 kΩ was desired for each electrode before recording started.

EEG Processing. Continuous EEG data were pre-processed offline using the MATLAB extension EEGLAB (Deloreme & Makeig, 2004) and the EEGLAB plugin 'ERPLAB' (Lopez-Calderon & Luck, 2010). Data were filtered with low and high bandpass at 0.05 – 40Hz, respectively (as in Poonian et al., 2015). Epochs for preaction potential began at 700ms before the first events and continued to 100ms after the first event. Preaction potential epochs were average baseline corrected at -700 to -500ms before the first event. Epochs for auditory ERPs began at 100ms before tone onset and continued until 500ms after tone onset. Auditory ERP epochs were average baseline corrected between -100 and 0ms. Trials in which the response to the probe letter was inaccurate were excluded from analysis. Epochs were rejected if they contained artifacts caused by poor signal, movement or blinks (artefact rejection = +/- 120 µV) and noisy channels were interpolated with the spherical interpolation function in the EEGLAB toolbox. This resulted in 71% of trials included for analysis on average per participant of trials for preaction potentials and 49% for auditory ERPs. 18% of trials for both preaction potentials and auditory ERPs were removed because the probe letter was not accurately identified as being present in the letters in the encoding stage. For preaction potential, a further 12% of trials were removed because they exceeded the artifact rejection criteria. For auditory ERPs, a further 33% were removed due to artifacts in the EEG data. The number of preaction potential epochs included in each condition were as follows: Agency Low: 49; Agency High: 34; No Agency Low: 51; No Agency High: 36. The number of auditory ERP epochs included in each condition were as follows: Agency Low: 34; Agency High: 30; No Agency Low: 31; No Agency High: 24. EEG data were re-

referenced to an average before individual's preaction potentials and auditory ERPs were created and averaged for each condition.

Readiness potential. Event preceding neural activity was measured. In Agency conditions the event was the keypress, and in No Agency conditions the event was the onset of the first tone. Mean amplitudes for each electrode of interest (Fz and Cz) were taken across the five Time Intervals of 100ms each, beginning at 500ms before the first event.

Auditory ERPs. Mean amplitudes were calculated for the N1 and P2 components across two frontocentral electrodes (Fz and Cz). Time windows centred around the peak of the grand-average waveform for all conditions were used: for the N1 component the time window was 120 – 180ms, for the P2 component the time window was 180 – 280ms.

Results

Reproduction error

Two participants were removed from analysis due to experimenter error in the administration of the block order whereby in each experiment one condition was run for three blocks and another condition was run just once. One additional participant was removed for having extreme average reproduction errors (> 3*SDs* of grand average reproduction errors). A total of 0.3% of trials were removed as outliers. The remaining data were analysed using a 2 (Presence of Agency) X 2 (Mental Effort) ANOVA (see Figure 15). This revealed a main effect of Presence of Agency, $F(1, 34) = 22.9$, $p < .001$, $\eta p^2 = .402$, with larger reproduction errors during Agency compared with No Agency conditions (M = -317ms, SD = 196, and M = -119ms, SD = 289, respectively). Both the main effect of Mental Effort and the interaction were not significant, $F(1, 34) = .593$, $p = .447$, $\eta p^2 = .017$ and $F(1, 34) = .005$, $p = .944$, $\eta p^2 < .001$, respectively.

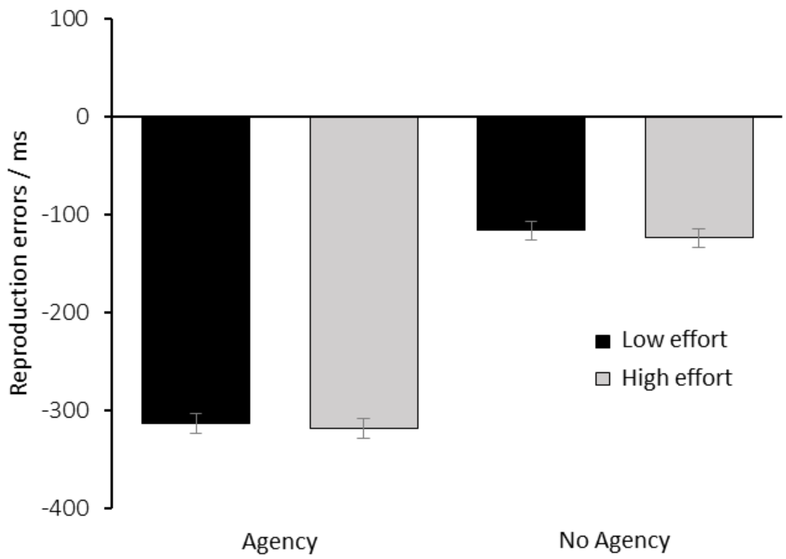

Figure 15. Mean reproduction errors across the Presence of Agency and Mental Effort manipulations. Bars extending below the x-axis reflect an underestimation of the stimulus interval (temporal binding).

As in the four previous experiments, the performance on the first and second halves of the experiment were compared with the factor 'Time on Task'. The three-way interaction was non-significant, F(1, 34) < .09, meaning that the effect of effort on agency was consistent across the experiment session.

Readiness potentials

A 5 x 2 x 2 x 2 four-way repeated measures ANOVA (Time Intervals x Presence of Agency x Mental Effort x Scalp Location; see Figure 16 and 17) showed significant main effects of Time Intervals, Presence of Agency and Electrode: $F(4, 136) = 18.48$, $p < .001$, $\eta p^2 = .35$, $F(1, 34) = 4.77$, $p = .036$, $\eta p^2 = .12$ and $F(1, 34) = 9.75$, $p = .004$, $\eta p^2 = .22$. These effects were due to rising negativity across the Time Intervals such that intervals -200 to -100ms and -100 to 0ms produced more negative average amplitude than the three intervals spanning from -500 to -200ms: *ts* > 2.14, *ps* < .04, $d_z s > .35$. The negativity for the interval -100 to 0ms was also greater than the interval -200 to -100ms: $t(34) = -5.77$, $p < .001$, $d_z = .98$. There was also greater negativity under Agency conditions compared to No Agency conditions ($M = -.73$ µV, $SD = .86$, and $M = -.34$ µV, $SD = .97$, respectively): $t(34) = -2.19$, $p = .036$, $d_z = .37$ and greater negativity at electrode Fz compared to Cz (M = -.89 μV, SD = 1.22, and M = -.18 μV, SD = .74, respectively): $t(34) = -3.12$, $p = .004$, $d_z = .53$.

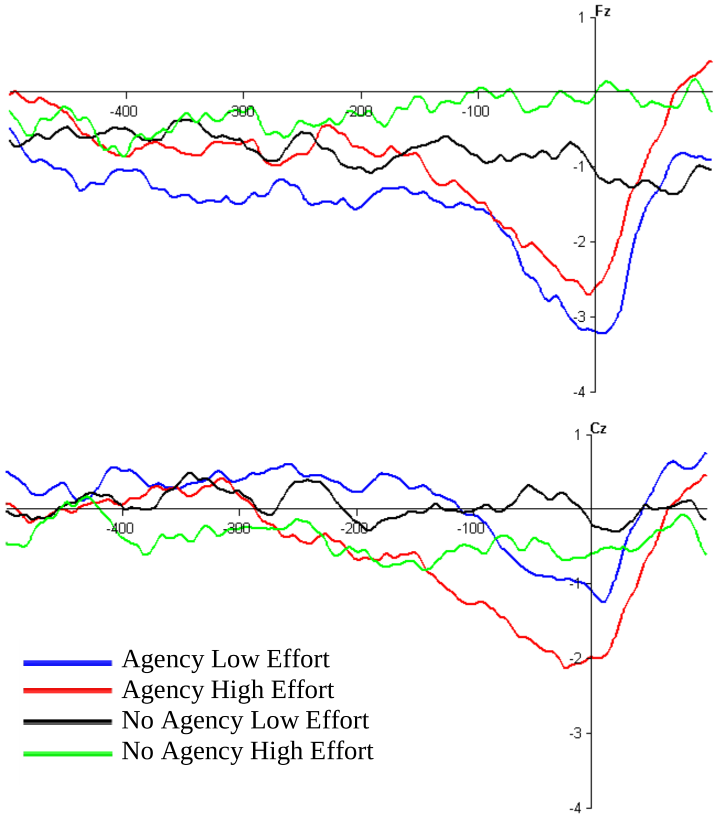

Figure 16. The Readiness Potential ERP component waveplot across Presence of Agency, Mental Effort and Scalp Location manipulations. There is increasing negativity up until the execution of the keypress action in Agency conditions, but not in No Agency conditions.

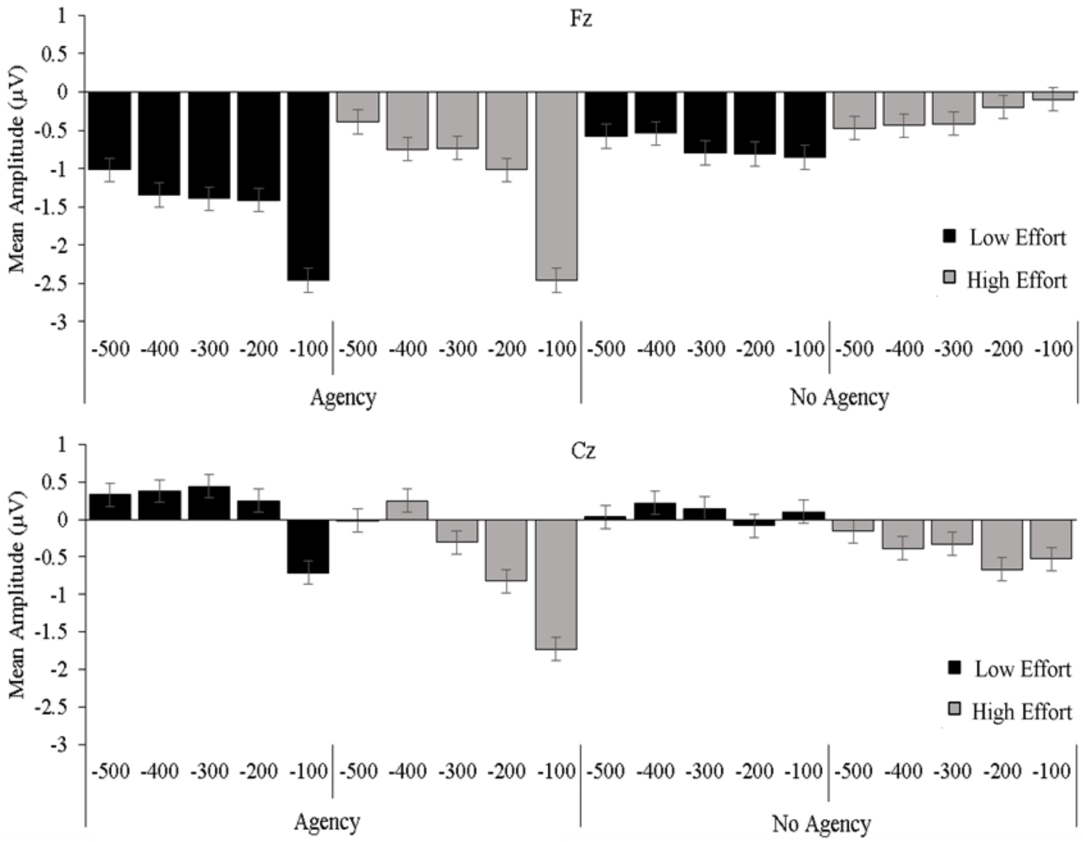

Figure 17. Mean Amplitude of the event preceding activity across the Presence of Agency, Mental Effort, and Time Interval manipulations at electrode locations Fz and Cz. The First event occurred at 0ms and was either a keypress (Agency) or a tone (No Agency). In Agency conditions mean amplitude negativity increases across the time intervals. Cz is also sensitive to the Mental Effort manipulation whereby mean amplitude is more negative under High effort compared with Low effort. This effect is not consistent at Fz.

As predicted, there was a significant Time Interval x Presence of Agency interaction, $F(4, 136) = 20.17$, $p < .001$, $\eta p^2 = .37$. Two one-way repeated measures ANOVAs determined that the there was no effect of Time Interval under conditions of No Agency, $F(1, 34) = .26$, $p = .62$, $\eta p^2 = .008$, whereas this effect was significant under Agency conditions, $F(1, 34) = 57.66$, $p < .001$, $\eta p^2 = .63$, with the same contrast effects found in the main effect of Time Interval. For Agency conditions, intervals -200 and -100 produced more negative average amplitude than the three intervals spanning from -500 to -200ms: *t*s > 2.23, *p*s < .023, d_zs > .37. The negativity for the interval -100 was also greater then interval -200: $t(34) = -8.7$, $p < .001$, $d_z = 1.45$.

Of particular interest to the research questions is the significant Time Interval x Presence of Agency x Mental Effort interaction, *F*(1, 136) = 2.84, *p* = .027, ηp^2 = .8 . Five 2 x 2 (Presence of Agency x Mental Effort) two-way repeated measures ANOVAs indicated however, only a significant main effect of Presence of Agency on -100 to 0ms Time Intervals, *F*(1, 34) = 29.6, *p* <.001, ηp^2 = .47, whereby only at the interval -100 to 0ms before the first event was the mean amplitude significantly more negative under Agency conditions compared to No Agency conditions (*M* = -1.76 μV, *SD* = 1.07, and *M* = -.35 μV, *SD* = 1.35, respectively). No remaining main effects or interactions were significant. For the main effect of Presence of Agency: -500ms: *F*(1, 34) = .016, *p* =.9, ηp^2 < .001; -400ms: *F*(1, 34) = .22, *p* =.64, ηp^2 = .006; -300ms: *F(*1, 34) = .003, *p* = .96, ηp^2 < .001; -200ms: *F*(1, 34) = 1.7, *p* =.2, ηp^2 = .048. For the main effect of Mental Effort: -500ms: *F*(1, 34) = .1, *p* =.75, ηp^2 = .003; -400ms: *F*(1, 34) = .003, *p* =.96, ηp^2 < .001; -300ms: *F*(1, 34) = 1.22, *p* = .28, ηp^2 = .035; -200ms: *F*(1, 34) = .47, *p* =.5, ηp^2 = .01; -100ms: *F*(1, 34) = .22, *p* = .65, ηp^2 = .006. For the interaction: -500ms: *F*(1, 34) = .52, *p* =.48, ηp^2 = .015; -400ms: *F(*1, 34) = 1.86, *p* =.18, ηp^2 = .05; -300ms: *F*(1, 34) = 1.09, *p* = .31, ηp^2 = .031; -200ms: *F*(1, 34) = .65, *p* =.43, ηp^2 = .02; -100ms: *F*(1, 34) = .76, *p* = .39, ηp^2 = .022.

The Mental Effort x Scalp Location interaction was also significant, *F*(1, 34) = 9.55, *p* =.004, ηp^2 = .22, because at Cz High Effort tasks produce more negative mean amplitude compared to Low Effort tasks, *t* (34) = -2.69, *p* = .011, d_z = .45. This effect was not consistent at Fz, t (34) = 1.54, p = .13, d_z = .26. For low effort mean amplitude was also more negative at Fz compared to at Cz, *t* (34) = 4.38, *p* < .001, d_z = .74. This effect was not consistent under high effort, *t* (34) = -.68, *p* = .5, d_z = .11. This may indicate that Cz is sensitive to the Mental Effort manipulation.

The Time Interval x Mental Effort x Scalp Location interaction was also significant, *F*(4, 136) = 2.52, *p* =.044, ηp^2 = .069, and further clarifies the Mental Effort x Scalp Location analysis above (Figure 18). To determine the source of this significant three-way interaction, five 2 x 2 (Mental Effort x Scalp Location) repeated measures ANOVAs were run across the five levels of Time Interval. There were significant main effects of Mental Effort across all time intervals because the mean amplitude was more negative under conditions of Low Mental Effort compared to High Mental Effort, *Fs* > 9.62, *ps* <.025, except for the 100ms interval starting 200ms before the first event which was marginally significant, *F* = 3.63, *p* = .065. The main effect of Scalp Location was non-significant across all time intervals, *Fs* < .003, *ps* >.5. The interaction was significant across all time intervals: *Fs* > 6.3, *ps* <.017, because, as in the Mental Effort x Scalp Location interaction above, for low effort mean amplitude was less negative at Cz compared to at Fz, *ts* >3.43, *ps* < .002. This effect was not consistent in high effort conditions, *ts* < 1.74, *ps* > .081. Interestingly, unlike for the significant main effect of Mental Effort showing greater negativity during Low Effort tasks, at scalp location Cz mean amplitude becomes more negative for High Effort tasks compared to Low Effort tasks, across time. At -500ms this effect is non-significant, $t\ (34) = 1.66$, $p = .106$, $d_z = .28$, at -400ms this effect is marginally significant, -400ms: $t\ (34) = 1.99$, $p = .055$, $d_z = .34$, and at the remaining three intervals this effect is significant: -300ms: $t\ (34) = 2.3$, $p = .026$, $d_z = .39$; -200ms: $t\ (34) = 3.09$, $p = .004$, $d_z = .52$; -100ms: $t\ (34) = 2.3$, $p = .028$, $d_z = .39$. There were no significant differences in mean amplitude across Low and High mental effort conditions at any time interval at location Fz, *ts* < 1.69, *ps* > .1. These patterns of data further indicate that scalp location Cz may indicate sensitivities to the Mental Effort manipulation.

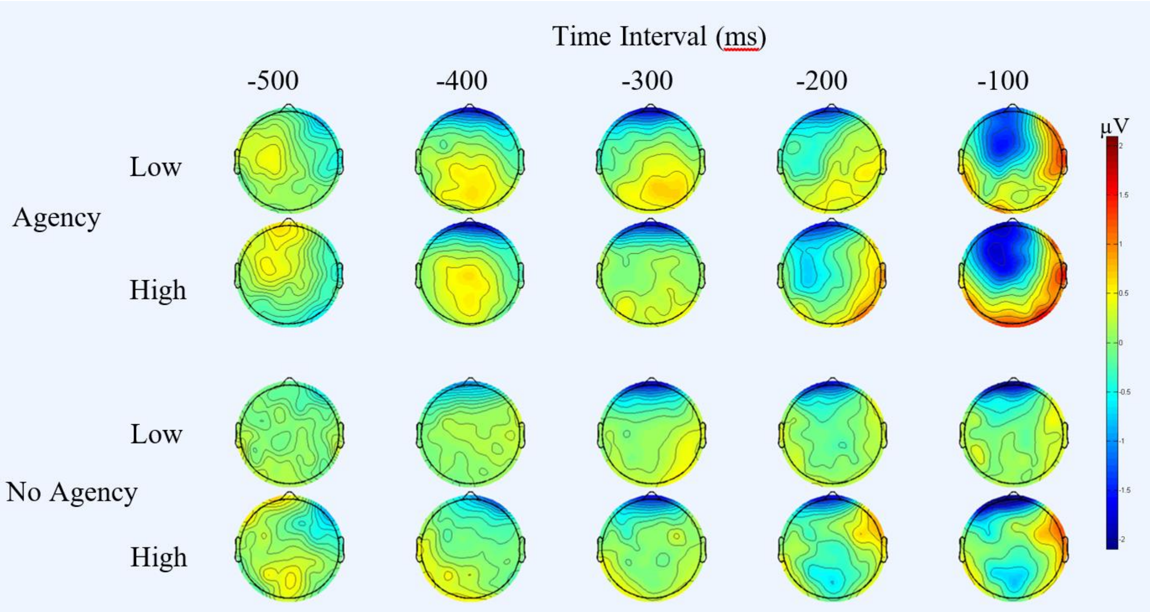

Figure 18. Mean Amplitude scalp maps of action preceding EEG activity across Presence of Agency and Mental Effort manipulations for the five 100ms Time Intervals. In Agency conditions negativity increases over the time intervals. Negativity is also greater at location Cz under High Effort conditions.

There was no main effect of Mental Effort, $F(1, 34) = .09$, $p = .77$, $\eta p^2 = .003$. The Time Interval x Mental Effort, Presence of Agency x Mental Effort, Time Interval x Scalp Location, and Presence of Agency x Scalp Location interactions were also not significant, $F(4, 136) = .56$, $p = .69$, $\eta p^2 <.001$, $F(4, 136) = .002$, $p = .96$, $\eta p^2 < .001$, $F(4, 136) = 1.42$, $p = .23$, $\eta p^2 = .04$, and $F(4, 136) = 3.17$, $p = .08$, $\eta p^2 = .09$, respectively. The Time Interval x Presence of Agency x Scalp Location, and Presence of Agency x Mental Effort x Scalp Location interactions were additionally non-significant, $F(4, 136) = .703$, $p = .59$, $\eta p^2 = .02$, and $F(1, 34) = .28$, $p = .6$, $\eta p^2 = .008$, respectively. The Four-way interaction, Presence of Agency x Mental Effort x Scalp Location x Time Interval, was also not significant, $F(4, 136) = .51$, $p = .73$, $\eta p^2 = .02$.

As a secondary analysis to further investigate the role of the factors Presence of Agency, Mental effort and Scalp location on cortical negativity specifically at the crucial 100ms prior to the event (-100ms), these factors were analysed using a 2 x 2 x 2 ANOVA. Mirroring the patterns of data in the primary analysis, main effects of Presence of Agency and Scalp Location were observed, $F(1, 34) = 29.63$ $p < .001$, $\eta p^2 = .47$, and $F(1, 34) = 5.54$ $p = .024$, $\eta p^2 = .14$, and the Mental Effort x Scalp Location interaction was significant, $F(1, 34) = 32.78$ $p = .014$, $\eta p^2 = .16$, Of greater interest is the three-way interaction, which was non-significant, $F(1, 34) = .005$ $p = .97$, $\eta p^2 <.001$. All other main effects and interactions were not significant, $Fs < 1.4$, $ps >.25$.

Readiness potential and reproduction error. To determine if the event preceding neural responses reflect the degree of implicit sense of agency the relationship between the mean amplitude at time interval -100ms and reproduction error was examined within the four conditions across Presence of Agency and Mental Effort manipulations. This relationship was examined across both scalp locations, and separately for Fz and Cz. None of the twelve Pearson's correlations revealed significant effects ($-.15<r>.11$, $ps > .4$). The relationship between -100ms Amplitude Differential and Reproduction Error Differential was also examined. A Pearson correlation revealed a non-significant relationship between the two variables when data are averaged across scalp locations, and analysed separately for Fz and Cz, $r(33) = .038$, $p = .83$, $r(33) = .096$, $p = .585$, and $r(33) = -.06$, $p = .73$.

Readiness potential and accuracy scores. As a secondary analysis, the individual levels of task difficulty were also considered for their role in modulating the action preceding negativity. Task accuracy scores were therefore correlated with mean amplitude within conditions across the Presence of Agency and Mental Effort manipulations at the 100ms time interval preceding the event (see Figure 19). Mean amplitude was primarily collapsed across Scalp Location, although the correlations are also provided for Fz and Cz separately (see Table 1). As expected, there were no significant relationships between accuracy score and mean amplitude in No Agency conditions. Interestingly, for High Mental Effort tasks under Agency conditions, Pearsons correlations showed a significant negative relationship between task accuracy and mean amplitude. This relationship is such that mean amplitude is more negative as task accuracy increases. These effects are also somewhat reflected when just examining mean amplitude at scalp location Fz, but are not significant at Cz. These effects were not consistent in Agency Low Effort conditions. Moreover, no significant relationship was observed when correlating accuracy scores with mean amplitude in Agency Low effort conditions.

The relationship between -100ms Amplitude Differential and Accuracy Difference was additionally examined. Pearsons correlations revealed non-significant relationships, when scalp location was collapsed and separately at Fz and Cz, $r\ (33) = .21$, $p = .23$, $r\ (33) = .12$, $p = .49$, and $r\ (33) = .18$, $p = .3$, respectively.

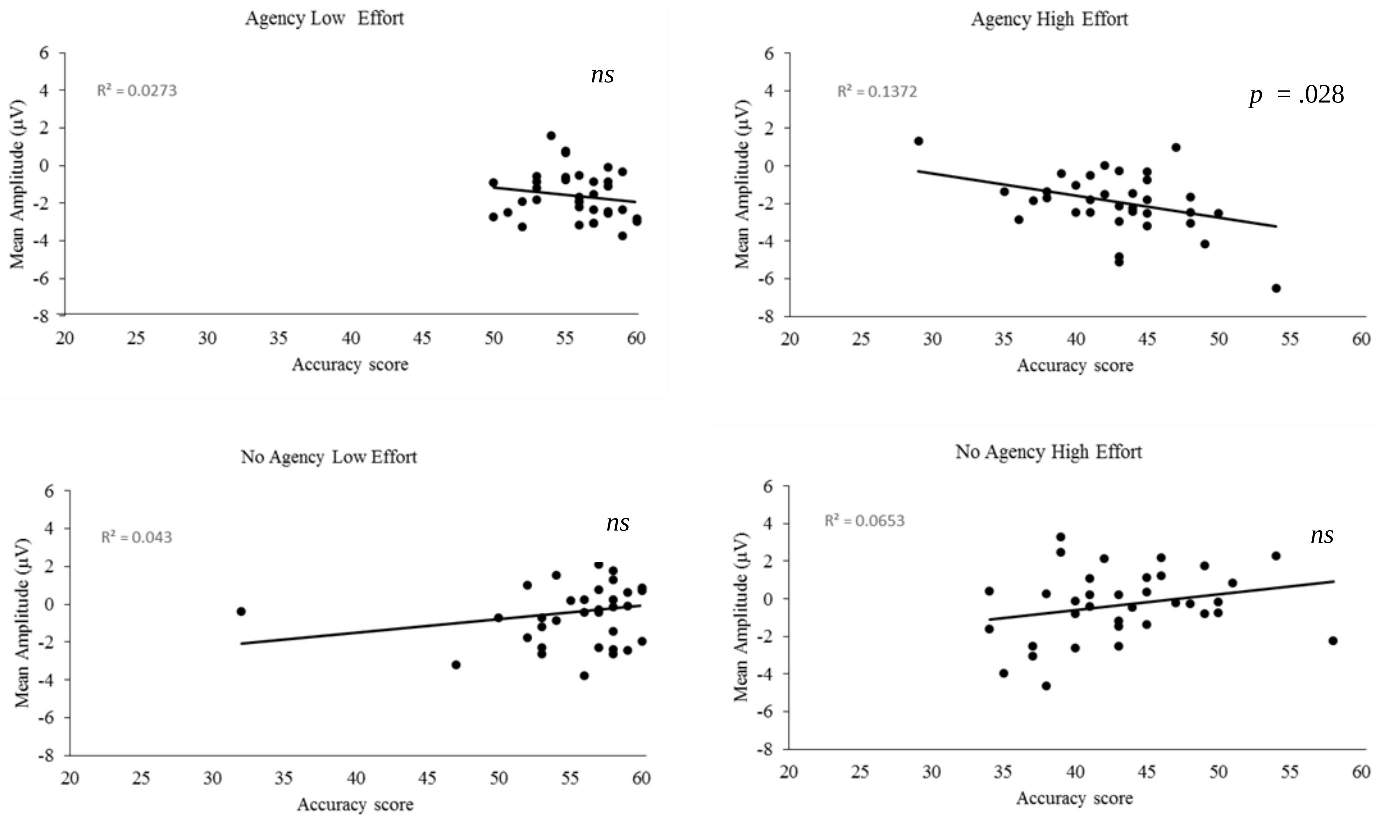

Figure 19. The relationship between accuracy scores and mean amplitude of brain activity at the 100ms time interval preceding the event across the Presence of Agency and Mental Effort manipulations, collapsed across scalp location. Under Agency High Effort conditions there is a significant negative correlation such that as accuracy increases, mean amplitude becomes more negative.

Table 1

Correlation coefficients and p values of Pearsons correlations between mean amplitude and accuracy scores at 100ms event preceding time intervals across Presence of Agency and Mental Effort manipulations, collapsed across Scalp Location, and separately at Fz and Cz.

	FzCz	Fz	Cz
	r, *p*	*r*, *p*	*r*, *p*
Agency Low	-.17, .34	.036, .84	-.21, .23
Agency High	-.37, **.028 ***	-.32, .059	-.2, .26
No Agency Low	.21, .23	.1, .59	.3, .08
No Agency High	.26, .14	.084, .63	.28, .1

Note. N = 35. * indicates *p* <.05.

Readiness potential analysis summary

As expected, the mean amplitude of neural activity became more negative preceding an action compared to preceding an auditory tone, with the 100ms interval immediately preceding the event (action or tone) particularly emphasising this effect. This is reflective of action preceding negativity of the readiness potential. The neural activity was also more negative at scalp location Fz, compared to Cz. High mental effort conditions also produced attenuated readiness potential compared with low mental effort tasks. However, it is evident that at scalp location Cz there is a sensitivity to the mental effort manipulation, because at this location mean amplitude became significantly more negative for High effort tasks than Low effort tasks, a pattern that was not consistent at Fz and which went against the pattern of the main effect of Mental Effort. This effect was consistent across both Agency and No Agency tasks, so no interaction between the factors Presence of Agency and Mental Effort was observed. The degree of negativity immediately preceding the first event also did not correlate with the implicit measure of agency, reproduction error. Secondary analysis further indicated that individual task difficulty modulates the degree of cortical negativity, because for High Mental Effort tasks under Agency conditions, as task accuracy increases mean amplitude becomes more negative. This effect was not consistent under the other conditions across the Presence of Agency and Mental Effort manipulations.

Auditory ERPs

N1 ERP component. A 3 x 2 x 2 three-way repeated-measures ANOVA (Tone x Mental Effort x Scalp Location; see Figures 20 & 21) showed significant main effects indicating differences in amplitude for the N1 ERP across Tone and Scalp Location, $F(2, 68) = 26.59$, $p < .001$, $\eta p^2 = .439$ and $F(1, 34) = 31.49$, $p < .001$, $\eta p^2 = .48$, respectively. To examine the main effect of Tone, three pairwise comparisons were conducted to compare N1 amplitude to 1) both tones in the No Agency condition, 2) the first tones i.e. the Agency tone and the first tone in No Agency conditions, and 3) the second event tones i.e. the Agency tone and the second tone in No Agency conditions. The first comparison (both tones in No Agency condition) indicates that N1 amplitude to the first tone in the No Agency condition was greater than for the second tone, $t(34) = 6.72$, $p < .001$, $d_z = 1.14$ ($M = -3.12$ μV, $SD = 1.02$ and $M = -1.75$ μV, $SD = .98$, respectively). This reflects neural adaptation to a repeated tone. The N1 amplitude for the first tone in Agency conditions was also significantly smaller than the first tone in No Agency conditions, $t(34) = 2.59$, $p = .014$, $d_z = .44$ ($M = -\ 3.12$ μV, $SD = 1.02$ and $M = -2.73$ μV, $SD = 1.05$, respectively). This reflects the neural suppression of the auditory tone following an action. The amplitude of N1 for the second events, i.e. the first tone in Agency conditions and the second tone in No Agency conditions, was also greater in Agency conditions compared to in No Agency conditions, $t(34) = -4.69$, $p < .001$, $d_z = .79$. The main effect of Scalp Location was driven by N1 amplitude being greater at electrode location Fz compared to Cz, $t(34) = -5.61$, $p <.001$, $d_z = .95$ ($M = -3.11$, $SD = .89$ and $M = -2.00$, $SD = 1.01$, respectively). There was no main effect of effort, $F(1, 34) = .56$, $p =.46$, $\eta p^2 = .016$., and no significant interactions: Tone x Mental Effort, $F(2, 68) = .918$, $p =.4$, $\eta p^2 =.026$, Tone x Electrode: $F(2, 68) = 2.14$, $p = .13$, $\eta p^2 = .059$, Mental Effort x Scalp Location: $F(1, 34) = 2.9$, $p = .16$, $\eta p^2 = .057$, and Tone x Mental Effort x Scalp Location: $F(2, 68) = .16$, $p = .85$, $\eta p^2 = .005$.

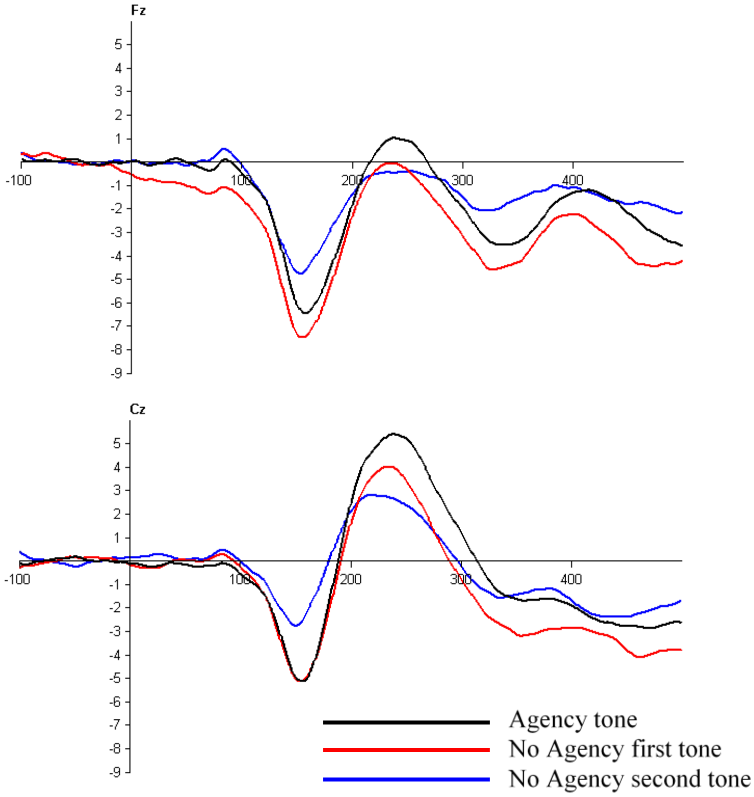

Figure 20. ERP waveplots across Scalp Locations showing the mean N1 amplitude time-locked to either the tone in Agency conditions, or the first or second tone in No Agency conditions.

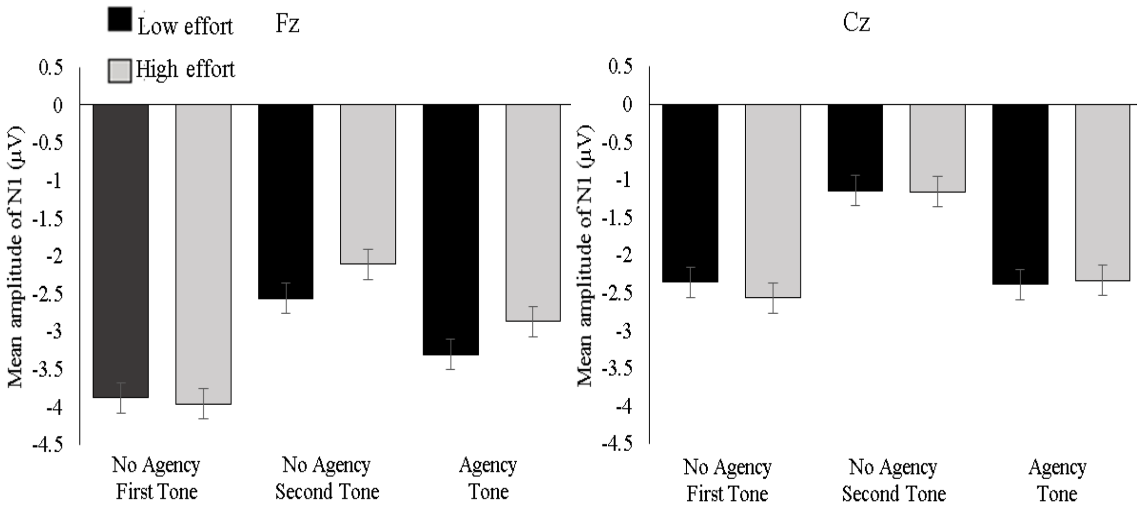

Figure 21. Mean amplitude of the N1 ERP responses across the factors Tone, Mental Effort and Scalp Location.

N1 and reproduction errors. To determine if there is a relationship between the N1 ERP and the degree of implicit sense of agency the relationship between N1 mean amplitude and reproduction error was examined within the four conditions across Presence of Agency and Mental Effort manipulations, as in the corresponding analysis for readiness potentials and reproduction errors. This relationship was examined across both scalp locations, and separately for Fz and Cz. None of the twelve Pearson's correlations revealed a significant relationship between N1 amplitude and reproduction errors (-.28 <*r*> .09, *p*s > .11). Furthermore, N1 Amplitude Differential was correlated with Reproduction Error Differential. A Pearson correlation revealed a non-significant relationship between the two variables when data are averaged across scalp locations, and analysed separately for Fz and Cz, $r(33) = .065$, $p = .71$, $r(33) = .06$, $p = .74$, and $r(33) = .04$, $p = .84$.

N1 and accuracy scores. As for the readiness potential analysis above, task accuracy scores were examined for their relationship with N1 amplitude. Accuracy scores were correlated with N1 mean amplitude within conditions across the Presence of Agency and Mental Effort manipulations across both scalp locations, and separately for Fz and Cz. The twelve Pearsons correlations revealed non-significant relationships between N1 amplitude and accuracy scores, (-.31 <*r*> .18, *p*s > .07). The relationship between N1 Amplitude Differential and Accuracy Difference also revealed non-significant relationships, when scalp location was both collapsed and analysed separately at Fz and Cz, $r\ (33) = -.301$, $p = .08$, $r\ (33) = -.14$, $p = .43$, and $r\ (33) = -.31$, $p = .07$, respectively.

N1 ERP analyses summary. The mean amplitude of the N1 ERP time-locked to each of the three tones (Agency tone, No Agency first tone and No Agency second tone) indicated towards the expected neural responses under the conditions. N1 was supressed for Agency tones, reflecting the neural suppression of events following an action, and N1 was supressed for the No Agency second tone, reflecting neural suppression of a repeated tone. N1 amplitude was greatest at scalp location Fz compared to Cz, but there was no influence of the Mental Effort manipulation. Moreover, despite prior evidence for such an effect, here the N1 amplitude was to found to correlate with neither reproduction error, the implicit measure of the sense of agency, nor individual task difficulty.

P2 ERP component.

To examine the P2 component a 3 x 2 x 2 ANOVA (Tone x Mental Effort x Scalp Location; see Figure 22) was run, which revealed significant differences in P2 amplitude across the factor Tone $F(2, 68) = 7.1$, $p = .002$, $\eta p^2 =.17$, and Scalp Location , $F(1, 34) = 93.59$, $p <.001$, $\eta p^2 =.734$. These significant main effects were driven by the mean P2 amplitude being greater for the Agency tone (*M* = 1.1 μV, *SD* = 1.5) compared with the No Agency first (*M* = .28 μV, *SD* = 1.4) and second tones (*M* = .49 μV, *SD* = 1.24), *t*(34) = 3.37, *p* = .002, d_z = .57, and *t*(34) = 3.02, *p* = .005, d_z = .51, respectively. P2 amplitude did not differ across the first and second No Agency tones, *t*(34) = .906, *p* = .3.7, d_z = .15. The mean P2 amplitude was also greater at Cz compared to at Fz, *t*(34) = 9.67, *p* < .001, d_z = 1.63 (*M* = 1.8 μV, *SD* = 1.28 and *M* = -.56 μV, *SD* = 1.44, respectively). No other main effects or interactions were significant: Mental Effort: *F*(1, 34) = 3.62, *p* = .066, ηp^2 =.096, Tone x Mental Effort: *F*(2, 68) = 5.026, *p* = .166, ηp^2 =.051, Tone X Scalp Location: *F*(2, 68) = 6.06, *p* = .121, ηp^2 =.06, Mental effort x Scalp Location: *F*(1, 34) = .71, *p* = .566 ηp^2 =.01; Tone x Mental effort x Scalp Location: *F*(2, 68) = 1.56, *p* = .44, ηp^2 =.024.

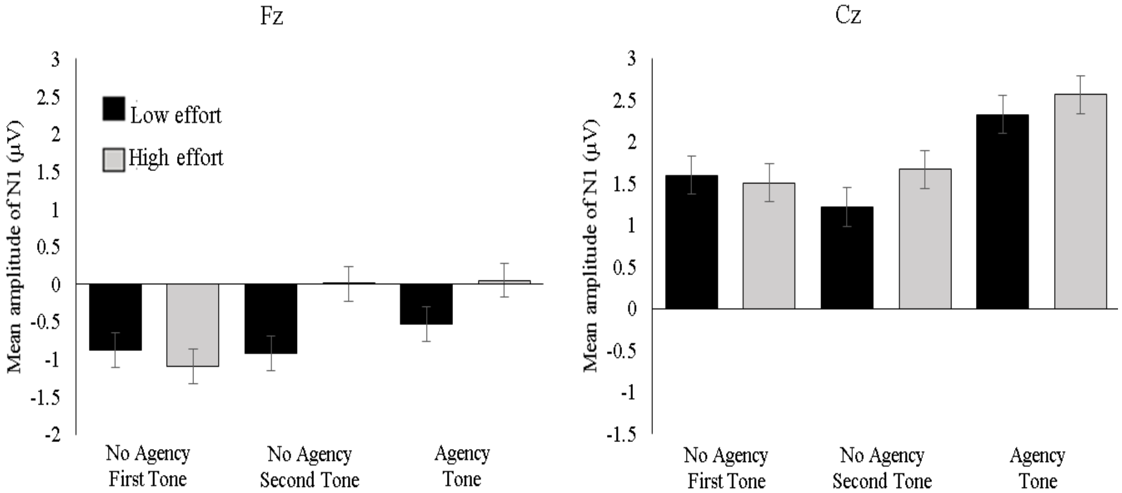

Figure 22. Mean amplitude of the P2 ERP responses across the factors Tone, Mental Effort and Scalp Location.

P2 and reproduction errors. As for the readiness potential and N1 amplitude, the relationship between P2 amplitude and the degree of implicit sense of agency was examined within the four conditions across Presence of Agency and Mental Effort manipulations, averaged across both scalp locations, and separately for Fz and Cz. None of the twelve Pearson's correlations revealed a significant relationship between P2 amplitude and reproduction errors (-.15 <*r*> .29, *p*s > .096). P2 Amplitude Differential was also correlated with Reproduction Error Differential, revealing non-significant relationships when data are averaged across scalp locations, and analysed separately for Fz and Cz, *r*(33) = -.09, *p* = .61, *r*(33) = -.1, *p* = .56, and *r*(33) = -.02, *p* = .9.

P2 ERP analyses summary. The mean amplitude of the P2 ERP time-locked to each of the three tones (Agency tone, No Agency first tone and No Agency second tone) was modulated by the Presence of Agency, such that P2 was greater for Agency tones compared to both No Agency tones. P2 amplitude was also modulated by Scalp Location, because at Cz mean amplitude was greater compared to at Fz. There was no effect of Mental Effort on P2 amplitude, and no relationship between P2 amplitude and reproduction error, and P2 amplitude and accuracy scores was found.

Discussion

The current study investigated the role of mental effort on an implicit measure of agency and the neural markers of this effect. Interval reproductions which are shorter than the actual delay experienced reflect temporal binding, whereby the two events are bound together in time. This effect is typically stronger under conditions of agency (Buehner & Humphreys, 2009; Engbert et al., 2007; Engbert & Wohlschläger, 2007; Haggard et al., 2002; Humphreys & Buehner, 2010). In Experiment 5, this effect was indeed replicated with a large effect size $\eta p^2 = .402$. Of critical interest, however, were the effects of effort on the implicit measure of agency, and how this modulates the readiness potential, N1 and P2 components. However, unlike in Chapter 4 there was no effect of mental effort on the degree of temporal binding, indicating that on this occurrence the mental effort manipulation was not successful in modulating the implicit measure of agency.

The current experiment also used EEG to measure the neural activity, notably the readiness potential, leading up to the first event in trials (a keypress action in Agency conditions and a first tone in No Agency conditions), and the neural responses to the tones, in particular, the N1 and P2 ERPs. The degree of temporal binding under each condition was also analysed to determine if the degree of reproduction error is related to the degree of neural activity. However, no relationship between temporal binding and the neural activity in the readiness potential, N1 and P2 were found.

The effect of the mental effort and agency manipulations were also examined for their role in modulating neural activity preceding an event. In Agency conditions the event was the keypress action, in No Agency conditions the event was the first tone. As predicted there was significant rising negativity in cortical activity 100ms preceding the keypress action, this is typical of the readiness potential and captures the preparation and planning of motor acts in the Pre-SMA (Libet et al.,1983; Shibasaki & Hallett, 2006). This effect was not observed in No Agency conditions, whereby there was no act for which to prepare. Interestingly, the effort manipulation also produced an effect on event preceding neural activity, in the predicted direction, whereby it is attenuated during high cognitive load tasks, as in Baker et al. (2011). This effect, however, was independent of agency conditions, but scalp location did provide insight into the modulatory role on the effect of effort, whereby, unlike the predicted main effect of high mental effort attenuating brain activity observed, at Cz there was greater negativity observed for *high* effort tasks, from 300ms preceding the action. Effect sizes for the critical interactions were small to medium (Time Interval x Presence of Agency: $\eta p^2 = .37$; Time Interval x Mental Effort x Scalp Location: $\eta p^2 = .069$), and the effect sizes of the key contrasts were medium to large (in Agency conditions -100ms interval vs. -200ms interval: $d_z = 1.45$; Low Effort vs. High Effort at Cz, -100ms: $d_z = .45$).

The role of individual task difficulty was also considered for its modulatory role on neural activity. To determine whether the event preceding activity was modulated by individual task difficulty, task accuracy scores were correlated with the mean amplitude of the 100ms interval immediately preceding the first event. As expected there was no relationship between these factors in No Agency tasks, in which no action was being prepared. However, interestingly, for high mental effort conditions the negativity was related to the degree of task accuracy, such that those with greater accuracy scores produced more negative readiness potential amplitudes, with the effect size of the correlation being medium, $r = -.37$. It should be noted however, that this effect was significant with an alpha value of .028, which was not corrected for in running multiple comparisons, and so should be interpreted with caution. If accuracy scores represent the ease at which the individual found the task then this may indicate that as accuracy scores increased, individual difficulty decreased. These data may therefore indicate that those who found the high mental effort manipulation more difficult, and thus, have to exert more cognitive resources to complete the task, have attenuated readiness potential due to the unavailability of resources to prepare an action. Whereas, those who found the high mental effort manipulation easier had a stronger readiness potential, which is believed to result from the more readily available resources with which to prepare an action. This would indeed make sense with what is expected, that readiness potential decreases under high cognitive load, believed to occur as a result of action preparation requiring cognitive resources (Baker et al., 2011). This reduced readiness potential under high effort appeared to be more robust at scalp location Fz than Cz, which may possibly highlight a neural sensitivity of individual task difficulty, manifesting towards more frontal regions.

This pattern of data therefore offer limited evidence for the role of mental effort attenuating the readiness potential when under conditions of agency.

Experiment 5 also used EEG to record neural responses to action outcomes (in Agency conditions, a tone following the keypress) and action unrelated tones (in No Agency conditions, the two tones). The neural responses of interest to the current experiment were the mean amplitudes of the N1 and P2 ERPs. As predicted, the mean amplitude of the N1 ERP time-locked to the tone was sensitive to the agency manipulation which showed that the agency manipulation was successful at a neural level. The effect size of the critical interaction was large, $\eta p^2 = .439$, and the key contrasts had medium to large effect sizes: first vs. second No Agency tones: $d_z = 1.14$; Agency tone vs. No Agency first tone: $d_z = .44$.

The N1 ERP is believed to reflect the degree of neural processing of the stimulus, with greater amplitude reflecting greater neural processing, and the Presence of Agency manipulation here elicits this effect. As, predicted, the greatest N1 or processing of the auditory tone occurs when it was first presented in conditions absent of agency. The N1 amplitude to the second tone in no agency conditions was attenuated, which reflects the supressed processing of a repeated stimulus (Grill-Spector et al., 2006). Also as expected, the action generated tone also showed reduced neural processing compared with the first tone in no agency conditions. This effect occurs due to the dampening of neural processing for events that are expected to occur, in this case as a result of a preceding action (Ford et al., 2007; Ford et al., 2013; Horváth et al., 2012; Knolle et al., 2012; Knolle et al., 2013; Kuhn et al., 2014; Martikainen et al., 2005; Poonian et al., 2015; Timm et al., 2014; Sowman et al., 2012). It was predicted that high mental effort tasks would attenuate the N1 response to the action generated tone. However, the pattern of data here does not identify a modulatory role of mental effort on the attenuation of N1.

The agency manipulation did modulate the P2 ERP, however, not in the predicted direction. There is some evidence that the P2 is attenuated for self-initiated tones (Horváth et al., 2012; Knolle et al., 2012; Knolle et al., 2013; Sowman et al., 2012), or findings that P2 amplitude is not attenuated for self-initiated tones (Bäß et al., 2008; Poonian et al., 2015; Martikainen et al., 2005). However, the pattern of data in the current showed that the P2 amplitude is greater when the tone is preceded by an action under conditions of agency, than for the tones presented in No Agency conditions. The statistical effect size is medium for the critical interaction, $\eta p^2 = .17$, and medium for the key contrasts, Agency tone vs. first No Agency tone: $d_z = .57$; Agency tone vs. No

Agency second tone: $d_z = .51$. These effects may be accounted for by differences in the paradigm, for instance, due to measuring the implicit measure of agency and manipulating conditions of agency and mental effort the expected differential effects were observed only for the N1 component (as in Poonian et al., 2015). There was also no modulatory role of mental effort for the P2 component, however, to my knowledge, there is no literature that would suggest such an effect.

The role of physical and mental effort has been previously found to modulate the degree of temporal binding between actions and effects. In previous investigation, Chapter 4, conditions of high cognitive load were found to reduce temporal binding under conditions of agency. These patterns of data are proposed to reflect reduced cognitive resources available for the action monitoring system to ascertain agency. Evidence supporting this notion comes from motor awareness deficits as a function of cognitive resource reduction, and the role of motor awareness for agency attribution (Blakemore et al., 2001; Blakemore et al., 2002; Kannape et al., 2014; Lindenberger et al., 2000; Moore et al., 2009; Moore & Fletcher, 2012; Woollacott & Shumway-Cook, 2002). Further evidence directly measuring the sense of agency found that cognitive load reduces explicit judgements of agency over outcomes (Hon et al., 2013). Indirect evidence measuring temporal binding also indicates that cognitive resource depletion through cognitive conflict and coercion reduces temporal binding (Caspar et al., 2016; Greene et al., 2004; Yoshie & Haggard, 2013). The data observed in this experiment failed to replicate these effects under the conditions of the current investigation. This is further discussed.

Previous findings have indicated that tasks which pull on cognitive resources attenuate the readiness potential, and the N1 response to self-initated tones. For the effects on N1, the role of mental effort has been investigated indirectly whereby directing cognitive resources to an auditory stimuli has shown enhancing effects on the amplitude of the visual N1 (Hillyard et al., 1973). Diverting cognitive resources away from a visual stimuli has also shown to attenuate the visual N1 (Boksem et al., 2005), whilst acting under cognitively straining conditions such as coercion, also attenuates the auditory N1 (Caspar et al., 2016). The effect of mental effort modulating the N1 ERP is believed to reflect the reduction in processing of the stimuli, caused by the limited cognitive resources with which to process the stimuli when they are diverted to an alternative resource consuming task. It is also arguably plausible that limited cognitive resources would result in no attenuation of the N1 ERP should the action monitoring system require resources to indicate towards agency. If the action monitoring system cannot determine expected sensory effects of action then the sensory outcome is responded to as though it was not self-caused or expected, with a non-attenuated N1 component. With regards to the readiness potential, it has been found that attending to the intention to move enhances the negativity of the readiness potential (Lau et al., 2004), and directly burdening the cognitive system attenuates the negativity of the readiness potential (Baker et al., 2011). The neural negativity observed in the readiness potential is believed to reflect action planning, and action planning requires cognitive resources. Therefore, when burdening the cognitive system action planning becomes disrupted (Baker et al., 2011). It would therefore be expected that the manipulation of cognitive load in the current experiment would impact the neural activity reflecting the preparation to act and the processing of the action outcome (although, note that an indirect manipulation of mental effort examining the role of mediation on the readiness potential (Jo et al., 2014) did not find any effects). The current experiment can provide only limited evidence in support of this. Whilst the critical interactions regarding the effect of the effort under agency conditions were non-significant, an effect was observed regarding the readiness potential and the individual levels of task accuracy, which can be thought to index task difficulty and therefore how mentally effortful the mental effort manipulation was. This effect indicates that the less accurate, i.e. the more mentally taxing the high mental effort manipulation was, the more attenuated the negativity of the readiness potential was. This pattern of data therefore provides limited indirect evidence for the attenuating effect of mentally effortful tasks on action preceding neural activity.

Interestingly, under high mental effort, an effect was observed such that the readiness potential was attenuated. As previously addressed, this effect was predicted, with much literature to support this effect. However, at location Cz this effect was reversed, such that high mental effort conditions elicited greater readiness potential negativity. It is believed that this is the first instance of such an effect. This pattern of data may indicate that neural circuitry acts differentially under high cognitive load. During this study an action was always executed whilst under high cognitive load, therefore it can be assumed that some form of action planning was accounted for neurally. The effect of attenuated readiness potential at Fz and not at Cz, may be indicative of a more specific and more localised set of neural processes and circuitry involved with action planning during conditions of cognitive strain.

Limitations and further research

The current experiment did not observe a modulatory role of mental effort on reproduction error under Agency conditions, as was found in Experiment 4. These null effects are found despite the mental effort manipulation producing significantly more inaccurate responses for the high mental effort condition, compared with the low mental effort condition. Interestingly, in both experiment 4 and the current experiment, task accuracy was at 92% for the High mental effort condition, and 72% for the Low mental effort condition. The lack of the effect of the mental effort manipulation across levels of agency may therefore reflect differences in the experimental session. In the current experiment participants were additionally subject to EEG, however, it is not clear why this difference may have had a detrimental effect on the mental effort manipulation.

In order to examine the effect of mental effort and self-agency on the readiness potential, event preceding activity was measured. In Agency conditions the event was a keypress action, which was compared with No Agency conditions in which the stimulus preceding activity was time locked to the presentation of a predictably occurring tone. In No Agency conditions it is possible that distinct anticipatory neural activity, Stimulus Preceding Negativity, was occurring (van Boxtel & Böcker, 2004). The role of the Stimulus Preceding Negativity was not considered in the design, and was perhaps an oversight for its confounding effects of effort on the event preceding neural activity. Nevertheless, the design of the experiment aimed to match the delay of the onset of the voluntary keypress action with the onset of the first tone in No Agency conditions. A jittered delay between 300 – 500ms was therefore introduced which may have reduced the predictability of the onset of the tone, and thus may reduce the effect of anticipation. However, future research may aim to also avoid the effects of anticipatory Stimulus Preceding Negativity.

Despite the attenuation of the neural activity preceding action under high individual task difficulty, the disruption of the readiness potential impacted neither the implicit measure of the sense of agency, nor the neural response to the tone. This may indicate that there is a certain threshold of attenuated readiness potential that must be achieved before this reflects in behavioural measures and neural signatures of the sense of agency. Increasing the difficulty of the high mental effort task may be one manipulation that could highlight this.

The current study also used task accuracy as an index for an individual measure of the difficulty of the mental effort manipulation. It is possible that this measure may instead index the level of engagement with the task. To overcome this, explicit ratings of task difficulty regarding the mental effort manipulation may need to be collected with which to correlate with accuracy scores and the readiness potential to determine with more validity the modulatory role of individual task difficulty.

Here, an implicit temporal binding measure was used which has strong evidence in support of indexing the sense of agency, be it, feelings of agency. The sense of agency is made up of both feelings of agency and judgements of agency, which refer to the explicit agency reports, and evidence has shown that these sub-components of the sense of agency can be dissociated. It would therefore be of value to include explicit ratings of agency in future research, to determine the conditions in which feelings and judgements of agency diverge. This may be also particularly informative when studying the neural signatures of agency.

The pattern of data here also show that scalp location Cz may indicate sensitivities to cognitive burden during action planning. This is a notion that requires further empirical investigation and support which may offer valuable insight into how neural processes manage actions under conditions of cognitive strain.

Applications

The current research tentatively indicates that high individual task difficulty modulates the attenuation of the readiness potential. These findings provide a neural signature of how actions under limited cognitive resources, for instance, such as stress, fatigue and whilst multitasking, may disrupt the generation of agency over action-outcome relationships. The current research, and further research in this field can therefore shed light on how the sense of agency comes about at a neural level, and also whether the disruptive effect of mental effort on the sense of agency is due to disruptions to the neural response of action outcomes, or due to the disruption of action planning. This would be of interest when considering responsibility and culpability of actions under mental strain, because the timing of the mental strain may be paramount to the awareness of action outcomes.

Conclusion

The data presented in Experiment 5 show the neural signatures typically overserved under conditions of agency. That is, attenuated readiness potential and N1 neural responses. Limited evidence was found for the role of mental effort disrupting action preceding neural activity for motor planning and is such that the attenuation of the readiness potential was modulated by individual task difficulty of the high effort task.

There was no modulating role of mental effort in agency conditions for the amplitude of N1 and P2. This is mirrored in the failure to observe mental effort effects for agency in the behavioural responses. Interestingly, a novel effect was observed in which scalp location Cz indicates a sensitivity to the mental effort manipulation preceding an event. This was explained in terms of neural specificity in action planning under conditions of cognitive burden, yet further empirical investigation is required to understand this effect. Further suggestions for future research are offered to clarify the role of mental effort for the sense of agency and its neural responses. Research in such a domain has potential to impact how responsibility under mental strain can be understood at a neural level.

Chapter 6: The role of individual differences in schizotypy on the sense of agency

The sense of agency, that is, the feeling or knowing that certain events in the world are a result of our own actions, occurs so seemingly effortlessly and rapidly that the awareness of this may not even enter consciousness. However, this processing of the relationship between actions and their consequences can sometimes go awry. Examples of this can be observed in the symptoms of schizophrenia, whereby individuals externalise authorship over events that were generated by the self. Here we investigate the relationship between schizotypy in a sub-clinical population and the sense of agency, using an implicit temporal binding measure.

One way to examine the intricacies of phenomena are to investigate instances in which the phenomena are atypical. The symptoms experienced by individuals with schizophrenia provide one such instance in which a sense of agency is abnormal. Schizophrenia is a disease that is characterised by abnormal reflections of the self which manifest as positive or negative symptoms, or cognitive dysfunction. Positive symptoms are characterised by the presence of experiences otherwise absent in healthy individuals such as delusions and hallucinations. Negative symptoms are characterised by the absence of experiences otherwise present in healthy individuals, such as blunted affect and anhedonia. Schneider (1959) describes a subset of positive symptoms that relate to self-disturbances, known as First Rank Symptoms (FRS). These FRS directly relate to the abnormal experiences of agency in schizophrenia and include passivity, delusions of control, delusions of influence and auditory hallucinations (Blakemore et al., 2002). There is also some evidence in support of gender differences in schizophrenia, believed to be somewhat driven by hormonal differences (Häfner, 2003; Ochoa, et al., 2012). For instance, in males the incidence of the disease is greater, and the age of onset is also earlier than in females. The prevalence of affective and positive symptoms is also much greater in females than males, and males are more likely to report negative symptoms than females (Ochoa et al., 2012; Thorup et al. 2014).

Schizophrenia is considered to be fully dimensional such that symptoms can span across a continuum from unobtrusive schizophrenia like symptoms to psychosis and schizophrenia spectrum disorders (Nelson et al., 2013). The unobtrusive schizophrenia like symptoms are identified through personality traits as well as certain behaviours and experiences that are typical in schizophrenia. This allows for the measure of individual differences in schizophrenia like traits, or schizotypy. Individual differences in schizotypy are considered a useful construct with which to examine schizophrenia spectrum disorders. Examining schizotypy can also be advantageous because of the challenges involved with attaining access to patient populations and executing procedures (Barrantes-Vidal et al., 2015; Lenzenweger, 2010). The investigation of individual differences in schizotypy and their role on the sense of agency therefore holds importance for furthering the understanding of agency deficits in schizophrenia. Despite this, existing investigation examining this relationship is somewhat limited (but see Dewey & Knoblich, 2014; Moore et al., 2011).

Typically, a sense of agency is believed to be generated in part through a forward model of motor control, as previously discussed. When efferent motor signals and predictions regarding effects match reafferent signals and the sensory processing of the outcome, this acts as a cue towards self-agency. However, when there is a mismatch between these predicted and actual sensory signals, this cue for self-agency is missing, and a sense of agency is not generated. In schizophrenia, this inability to create accurate predictions concerning voluntary actions and outcomes is believed to be the source of abnormal agency attributions due to the lack of this important agency cue. As such, the inaccurate predictions do not reliably match with the reafferent signals, causing agency to be attributed externally. This is reflected as the FRS such as delusion of control, delusions of influence and auditory hallucinations (Blakemore & Frith, 2003; Frith et al., 2000; Wolpert, et al., 1995).

Evidence from studies examining motor control and awareness provide support for the deficits in the forward model of motor control for misattributions of agency in schizophrenia. For instance, compared with healthy individuals patients are more likely to misattribute ownership of another’s hand movement, and are less able to detect angle rotations of their own arm movements during visual feedback (Dapratti et al., 1997; Garbarini et al., 2016, Synofzik et al., 2010). Patients also respond to self-tickling as though it was externally sourced (Blakemore et al., 2000). These deficits in agency attribution may be caused by prediction errors that, according to forward models of motor control, result in reduced motor awareness and reduced self-agency, but the timing of the prediction errors are also important. Koreki et al. (2015) found that in patients with schizophrenia motor predictions were processed later than in healthy control subjects, which may account towards the agency deficits in schizophrenia.

The above findings identify deficits in self-agency measured by motor control, proprioception and motor awareness, but self-agency inaccuracies are also observed when judgments specifically concerning the author of an action or consequence are explicitly made. Patients with schizophrenia report greater agency judgements for another’s hand movements, and self-initated movement of stimuli compared with healthy controls (Dapratti et al., 1997; Franck et al., 2001; Koreki et al., 2015; Maeda et al., 2012). Importantly, these deficits in motor control and judgements of agency are similarly reported for healthy individuals with high levels of schizotypy traits. For instance, movement prediction errors were positively correlated with schizotypy, and for those with high levels of schizotypy judgements of agency were weaker for cursor movements (Asai et al., 2008; Asai & Tanno, 2007). These findings suggest that deficits in agency may be caused by the impaired ability for the forward model of motor control to generate agency attributions correctly. Moreover, this impairment may act as a function of the degree of schizotypy.

As discussed previously, a sense of agency can be measured implicitly by examining the degree of temporal binding between the action and the outcome. Typically, in healthy individuals temporal binding is greatest between self-generated actions and their outcomes (Haggard et al., 2002). In patients with schizophrenia, this temporal binding effect is also observed, however, the degree of temporal binding between actions and outcomes is much larger than in healthy controls. This effect is known as ‘hyper-binding’ (Haggard et al., 2003; Voss, et al., 2010). The effect of hyper-binding is similarly observed when healthy participants are administered ketamine to induce perceptual disturbances akin to psychosis (Moore et al., 2011; 2013). The nature of hyper-binding between actions and outcomes in patients with schizophrenia may arise because of errors in motor prediction. It is found that motor predictions are processed later in patients (Koreki et al., 2015). This delay in motor predictions of an action may increase the contiguity between action signals and the outcome. This would result in a decrease in perceived proximity between the action and effect which in turn may result in the hyper-binding observed in patients with schizophrenia. Interestingly, using the Libet clock method to measure temporal binding, Haggard et al. (2003) found that patients with schizophrenia also bound together in time two action-unrelated sequential tones compared with healthy controls. This effect, however, has received little empirical and theoretical attention. This could call for a complementary explanation for agency deficits in schizophrenia to account for hyper-binding between events that are not related to action. For instance, explanations could be the misinterpretation of agency-unrelated events as being self-referential, as discussed above, or an explanation could be general deficits in the construction of subjective time.

It is known that individuals with schizophrenia experience deficits in time perception. For instance, patients are less able than healthy controls to judge temporal order and discriminate interval lengths. Importantly, patients also replicate intervals of sound sequences at a faster pace than healthy controls (Braus, 2002, as cited in Gómez et al., 2014; Papageorgiou et al., 2013). So the hyper-binding effect may reflect temporal binding that is additive to the binding observed due to deficits in time perception, or simply deficits in time percpetion, causing the exaggerated underestimation.

The effect of schizotypy on the implicit sense of agency is lesser studied. Using an interval reproduction temporal binding method, Dewey and Knoblich (2014) examined the role of schizotypy for implicit sense of agency by measuring levels of magical ideation, just one sub-trait of schizotypy. Significant effects of levels of magical ideation on temporal binding were not observed. Magical ideation refers to beliefs referring to causation from our own actions which are conventionally impossible, such as good luck charms, spiritual influences and paranormal beliefs (Deuri, 2012; Eckbald & Chapman, 1983). A possible reason as to the null effects may be that this measure of schizotypy records beliefs and experiences that appear broadly in line with FRS of schizophrenia, rather than real-life cause and effect relationships relevant to self-agency. Schizophrenia is also a complex disease and investigating schizotypal traits on one scale of magical ideation does not fully cover the extent of schizophrenia like experiences and behaviours. The question as to whether sense of agency is affected by schizotypal traits in the typical population is therefore considered to still require investigation.

Experiment 6: Schizotypy and the sense of agency

Experiment 6 examines the role of individual differences in schizotypy on the implicit sense of agency. Individual differences in schizotypy were measured using three standardised self-report scales believed to be reliable and valid measures of schizotypy. The measures used were the Schizotypal Personality Questionnaire – Brief, the Cardiff Anomalous Perceptions Scale and Mason's Short Scales for Measuring Schizotypy (Bell et al., 2006; Mason et al., 2005; Raine & Benishay, 1995). Implicit sense of agency was measured using an interval reproduction method of temporal binding, which is considered a reliable implicit index of the sense of agency (Buehner & Humphreys, 2009; Engbert et al., 2008; Humphreys & Buehner, 2010; Poonian & Cunnington, 2013). Using this measure, comparisons can be made as to the differences in temporal binding under conditions of agency and no agency across individuals low and high on levels of schizotypy.

The use of the interval reproduction method is similar to Dewey and Knoblich (2014) in which they investigted implicit sense of agency and how it is modulated by levels of schizotypy. Dewey and Knoblich, however, investigated the role of a scale measuring only magical ideation to extrapolate the effect of schizotypy on temporal binding. The current study therefore differs in this respect including measures that cover a range of schizophrenia like experiences and behaviours with greater regards to the action-outcome relationship relevant to self-agency.

Previous literature indicates that individuals with schizophrenia have deficits in time perception such that durations are underestimated as a function of the severitiy of their symptoms. This may account for the 'hyper-binding' effect between actions and their outcomes observed in schizophrenia patients. In this case it would be expected that individuals with high levels of schizotypy would show enhanced temporal binding under both Agency and No Agency conditions. Haggard et al. (2003) found that individuals with schizophrenia also show temporal binding between both action-related and action-unrelated events, which may be reflective of deficits in time perception. However, should there be a reduction in the difference in temporal binding between Agency and No Agency conditions in those with high levels of schizotypy, this would be demonstrative of a deficit in the ability to distinguish temporally between agency and no agency conditions, and not over-underestimations of time.

It should be noted that data were collected across two data collection stages. In the original data collection stage 17.6% of the sample consisted of males. So, the decision was made to analyse the female data separately (Experiment 6a) and reserve the male data for a separate experiment (Experiment 6b) for which additional male data was collected in a second data collection stage. This decision is further supported by the evidence towards gender differences in schizophrenia, such that females experience more positive symptoms, which manifest as deficits in self-agency (Blakemore et al., 2002; Häfner, 2003; Ochoa, et al., 2012; Thorup et al. 2014).

Experiment 6a

Experiment 6a aimed to investigate the effects of individual differences in schizotypy on the implicit measure of agency in females, using a temporal binding paradigm. Levels of schizotypy were assessed using three scales, the SPQ-B (Raine & Benishay, 1995), the CAPS (Bell et al., 2006), and SMSS (Mason et al., 2005). Deficits in temporal binding may manifest as hyper-binding, in which individuals with high levels of schizotypy, compared with low levels of schizotypy, show greater temporal binding across both Agency and No Agency conditions. The ability to distinguish temporally between action-related events (keypress and tone) and action-unrelated events (two tones) can also be understood by measuring the difference in temporal binding across Agency and No Agency conditions. If these binding difference scores are reduced for those with high compared to low levels of schizotypy this may reflect the inability to distinguish between instances of self-agency, and instances of action unrelated events.

Method

Participants

Sixty-one females aged 18 – 29 years (*M* = 19.95, *SD* = 1.8) recruited from the University of East Anglia, completed the experiment in return for course credit. Participants gave informed consent and were naïve as to the nature of the experiment. Participants were excluded if they suffered from any of the following: depression, anxiety, autism, brain injury, schizophrenia, attention deficit hyperactivity disorder, or substance abuse. Participants were additionally excluded if they had first degree family members diagnosed schizophrenia. Data from nine participants were excluded due to these exclusion criteria (therefore N = 52).

Materials

Participants completed the following scales measuring schizotypy and negative emotional states of depression, anxiety and stress. The scales were presented using Qualtrics survey software.

Schizotypal Personality Questionnaire – Brief (SPQ-B). The SPQ-B questionnaire (Raine & Benishay, 1995) contains 22 items across three subscales of schizotypy: cognitive-perceptual deficits, interpersonal deficits and disorganisation, and also gives a total scale score. Participants responded to each item by indicating 'Yes' or 'No'. 'Yes' responses were given a score of one. Scores therefore ranged between 0 and 22, whereby higher scores indicate higher levels of schizotypy.

Cardiff Anomalous Perceptions Scale (CAPS). The CAPS (Bell et al., 2006) is a 32 item questionnaire assessing perceptual anomalies relating to clinical psychosis, temporal lobe disturbance and chemosensation. Participants respond to each item by indicating 'Yes' or 'No'. 'Yes' responses were given a score of one. If participants respond 'Yes' then they are further required to indicate on three separate scales (0-4) how distressing, intrusive and frequent these experiences are. A score of 0 reflected 'not at all distressing', 'not at all distracting' or 'happens hardly at all', respectively, and a score of 5 reflected 'very distressing', 'completely intrusive' or 'happens all the time', respectively. Scores for the total CAPS scale range between 0 and 32. The range for each dimension of distress, intrusiveness and frequency range between 0 and 160. Higher scores reflect higher levels of perceptual anomalies, distress, intrusiveness, and frequency of the experiences. The data from this part of the scale was not used in data analysis, and so the scores for distress, intrusiveness and frequency are not further discussed.

Mason's Short Scales for Measuring Schizotypy (SMSS). The SMSS (Mason et al., 2005) is a 42 item questionnaire which assesses levels of schizotypy across four subscales: unusual experiences, cognitive disorganisation, introvertive anhedonia and impulsive nonconformity. Participants responded to each item by indicating 'Yes' or 'No'. 'Yes' responses were given a score of one. Scores range between 0 and 42 whereby higher scores reflect higher levels of schizotypy.

Depression Anxiety Stress Scales (DASS). The DASS (Lovibond & Lovibond, 1995) was administered as part of an unrelated research question for other experimenters, and so is not further discussed.

Apparatus and stimuli

A tone (150ms, 440Hz; created using Audacity® software) was presented using Logitech speakers. Visual stimuli were presented (black text on a white background) using E-Prime® software on either a Dell 1909W monitor (size: 19 inches; resolution: 1440 x 900; refresh rate: 60 Hz), or a BenQ monitor (size: 24 inches, resolution: 1920 x 1080, refresh rate: 60Hz).

Design

Participants completed two experimental block types differing across the factor Presence of Agency (Agency or No Agency). The duration of reproduction error was calculated as the duration of response intervals minus the duration of stimulus intervals. A ‘Binding Difference’ score was calculated as reproduction error during Agency conditions minus reproduction error in No Agency conditions. A more negative binding difference score therefore reflects greater temporal binding for Agency conditions compared to No Agency conditions, whereas a positive binding difference scores reflects greater binding for No Agency conditions compared to Agency conditions.

For each schizotypy scale participants were additionally allocated to either a Low or High Schizotypy Group, determined by lower and upper third scores, inclusive of equal scores. For the SPQ-B scale the Low Schizotypy Group was therefore comprised of 17 participants with scores from 0-3, and the High Schizotypy Group was comprised of 19 participants with scores from 7-13. For the CAPS scale the Low Schizotypy Group was comprised of 17 participants with scores from 0-1, and the High Schizotypy Group was comprised of 18 participants with scores from 3-11. For the SMSS scale the Low Schizotypy Group was comprised of 17 participants with scores from 0-10, and the High Schizotypy Group was comprised of 16 participants with scores from 15-23. The final samples for the analyses using participants in the upper and lower thirds of the scales are therefore as follows: SPQ-B: N = 36; CAPS: N = 36; SMSS: N = 33.

Levels of schizotypy were measured using the following scales: SPQ-B, CAPS, and SMSS (Bell et al., 2006; Mason et al., 2005; Raine & Benishay, 1995). Levels of depression, anxiety and stress were additionally measured using the DASS (Lovibond & Lovibond, 1995) but used for other experimenters who examined unrelated research questions, so the DASS scales is not discussed further.

Procedure

Administration of scales. The scales were administered as one questionnaire prior to the lab session and were, presented in the following order: SPQ-B, SMSS, CAPS, DASS. The questionnaire took approximately 15 minutes to complete.

Presence of Agency manipulation. The interval reproduction task procedure was the same as that in Experiments 1 and 2, see Figure 2 on page 46 for the interval reproduction task procedure. Each condition contained 60 trials and was presented in blocks of 20 trials with a self-paced rest period between each block. The order of block type was alternated between Agency and No Agency conditions. The order of the condition in the first block was counterbalanced across participants. The mean length of the jittered stimulus interval was comparable across the Agency and No Agency conditions, $t = 1$, $p = .32$. The experimental procedure lasted approximately 20 minutes. The interval reproduction task was completed during an hour long experimental session whereby two additional tasks were administered. The two additional tasks were run for data collection for other experimenters and investigated unrelated research questions so are not discussed further. The order of all three tasks were counterbalanced across participants.

Results

Eight further participants were removed from the data set resulting in a final sample size of 44. Of these eight, five participants were removed for acting erroneously (not carrying out the interval reproduction task as directed such that the participant did not hold down the spacebar to reproduce the perceived stimulus interval) during the temporal binding task. Three participants were removed because their mean reproduction error values exceeded +/- 3 *SD* from the group mean.

Schizotypy scores

Average scores were calculated for each of the schizotypy scales. For SPQ-B the average score (out of 22) was below the general average (Raine & Benishay, 1995), *M* = 5.82, *SD* = 4.1 and *M* = 9.5, *SD* = 5.3, respectively. For CAPS our average score (out of 32) was below the average (Bell et al. 2005), *M* = 3.0 *SD* = 3.89 and *M* = 7.3, *SD* = 5.8, respectively. For SMSS our average score (out of 42) was higher than the average score (calculated from Mason & Claridge, 2006), *M* = 12.64, *SD* = 5.45 and *M* = 8.4 (*SD* not available), respectively.

Reproduction errors

Trials with reproduction errors which exceeded +/- 3 *SD* from the mean were removed (0.3% of trials). The reproduction error data were analysed using a paired samples *t* test. In Agency conditions mean reproduction error was greater compared to in No Agency conditions, $t(43) = -10.18$, $p < .001$, $d_z = 1.53$ (*M* = -395ms, SD = 211, and *M* = -183ms, *SD* = 263, respectively). This indicates that the agency manipulation was successful.

To determine the effect of levels of schizotypy on temporal binding three 2 x 2 ANOVAs were run with the factors Presence of Agency (Agency and No Agency) and Schizotypy Group (Low and High; see Table 2). Results of the 2 x 2 ANOVAs revealed a main effect of Presence of Agency for all three of the schizotypy scales, as in the analysis above, whereby temporal binding was greater in Agency compared with No Agency conditions, SPQ-B: $F(1, 41) = 99.77$, $p < .001$, $\eta p^2 = .71$; CAPS: $F(1, 33) = 107.27$, $p < .001$, $\eta p^2 = .77$; and SMSS: $F(1, 30) = 62.64$, $p < .001$, $\eta p^2 = .68$.). The interaction was non-significant for both the SPQ-B and SMSS scales: SPQ-B: $F(1, 41) = 1.24$, $p = .3$, $\eta p^2 = .06$, and SMSS: $F(1, 30) = 1.58$, $p = .22$, $\eta p^2 = .05$, however, the interaction was significant for the CAPS scale: $F(1, 33) = 8.36$, $p = .007$, $\eta p^2 = .20$. Contrasts analyses however were not consistent, finding that the degree of temporal binding is not significantly different across Low and High CAPS groups for Agency (M = -421ms, SD = 187, and M = -383ms, SD = 244, respectively) and No Agency conditions (M = -141ms, SD = 275, and M = -226ms, SD = 262, respectively): $t(33) = -.51$, $p = .62$, $d_z = .09$ and $t(33) = .931$, $p = .34$, $d_z = .16$.

Table 2

Female data reproduction error across the factors Presence of Agency and Schizotypy Group for the SPQ-B, CAPS and SMSS measures of schizotypy.

		Reproduction Error (ms)	
		Agency *M (SD)*	No Agency *M (SD)*
SPQ-B	Low Schizotypy	-423 (225)	-196 (272)
	High Schizotypy	-430 (192)	-251 (255)
CAPS	Low Schizotypy	-421 (187)	-141 (275)
	High Schizotypy	-383 (244)	-256 (262)
SMSS	Low Schizotypy	-481 (163)	-269 (240)
	High Schizotypy	-371 (230)	-217 (253)

To determine the effect of levels of schizotypy on the difference between the degree of temporal binding across the Presence of Agency manipulation contrast analyses were run on the variable Binding Difference in the Low and High schizotypy groups for each schizotypy scale (see Figure 23). Interestingly, the degree of Binding Difference is significantly different across Low and High CAPS groups, with binding difference being greater in the Low compared to the High CAPS group, $t(33) = -2.89$ $p = .007$, $d_z = .51$ (M = -280ms, SD = 150, and M = -158ms, SD = 95, respectively). Despite the pattern of data trending in a similar manner, Binding Differences were not significantly different across Low and High schizotypy groups for SPQ-B and SMSS, $t(34) = -1.02$, $p = .32$, $d_z = .17$ and $t(30) = -1.23$, $p = .22$, $d_z = .22$, respectively.

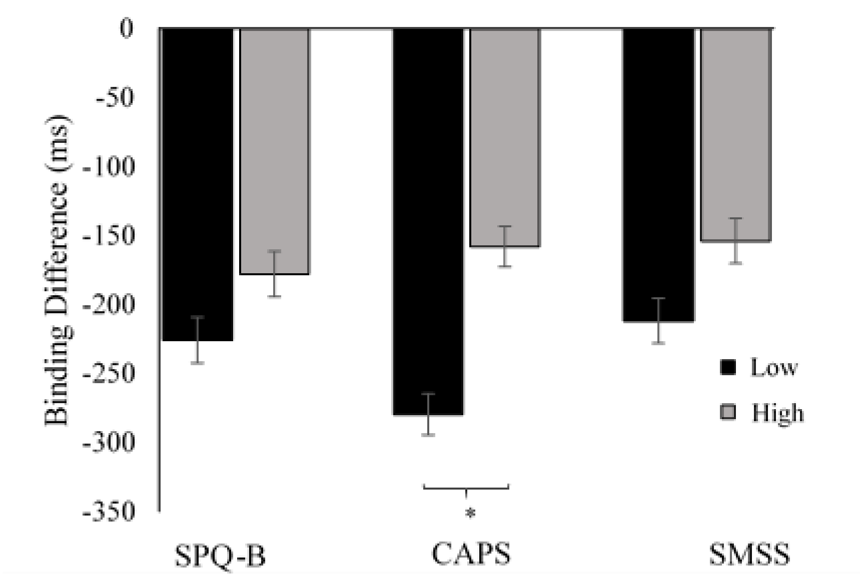

Figure 23. The Binding Differences across Low and High Schizotypy groups for the three scales, SPQ-B, CAPS and SMSS. The pattern of data shows a trend such that High Schizotypy groups show reduced Binding Differences, with the Binding Difference scores across Low and High CAPS groups being significantly different from each other.

Binding difference scores for the full sample were further submitted to Pearson's *r* correlations to determine the relationship between Binding Difference scores and levels of schizotypy. Significant correlations were found for SPQ-B, r (42) = .297, $p = .050$, and for CAPS, r (42) = .37, $p = .014$ (see Figures 24 & 25, respectively), whereby the difference in temporal binding across Agency and No Agency conditions reduced as schizotypy levels increased. The correlation between SMSS and Binding Difference Scores was not significant, r (42) = .12, $p = .439$ (see Figure 26).

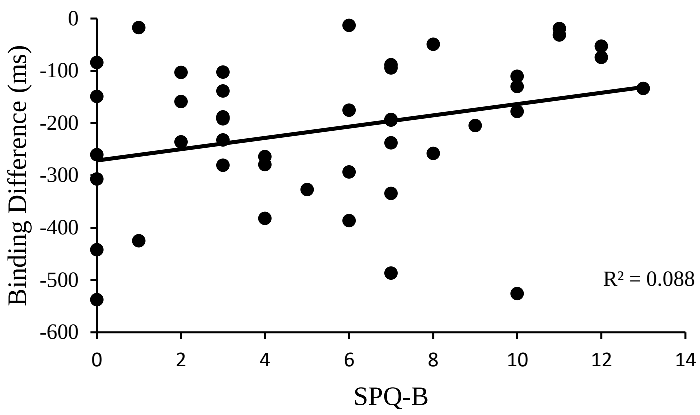

Figure 24. The significant relationship between SPQ-B score and Binding Difference score in females, r = .297.

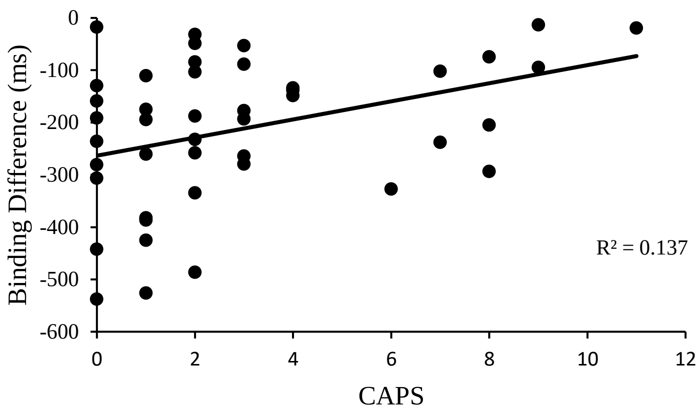

Figure 25. The significant relationship between CAPS and Binding Difference scores in females, r = .37.

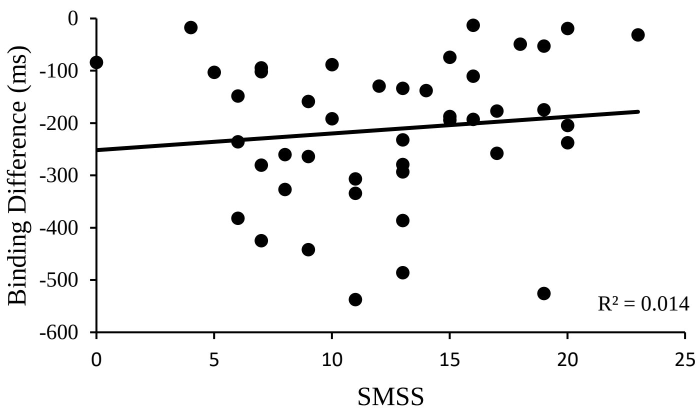

Figure 26. The non-significant relationship between SMSS and Binding Difference scores in females, r =.12.

In order to account for any variance in the levels of schizotypy in the three scales examined here, a principal components analysis (PCA) was run on the total scores of three measures of schizotypy (SPQ-B, SMSS and CAPS) to give one overall ‘Schizotypy’ variable. The relationship between this Schizotypy variable and the difference in temporal binding across Agency and No Agency conditions (Binding Difference) can then be explored. This analysis was run on the full female sample, N = 44. The suitability of PCA was assessed prior to analysis. Inspection of the correlation matrix showed that all variables had at least one correlation coefficient greater than 0.3. The overall Kaiser-Meyer-Olkin (KMO) measure was 0.57 with individual KMO measures all greater than 0.5. According to Kaiser (1974), the minimum value of overall KMO should be 0.6, and the individual KMO measures observed here are classified as ‘miserable’. The findings here should therefore be interpreted with caution. Bartlett's Test of Sphericity was statistically significant ($p < .001$), indicating that the data was likely factorisable.

PCA revealed one component, the factor Schizotypy, that had an eigenvalue greater than one, explaining 65.1% of the total variance. Visual inspection of the scree plot confirmed that one component should be retained (Cattell, 1966). Because only one component was extracted the components cannot be rotated. The component loadings and respective proportion of variance accounted for by each scale are as follows: SPQ-B: .91, 82%; SMSS: .87, 75%; and CAPS: .62, 38%.

The relationship between the factors scores of this new Schizotypy factor and Binding Difference was examined, revealing a significant negative relationship, r (42) = .31, $p = .042$ (see Figure 27). This indicates that those with high Schizotypy scores showed lesser Binding Difference such that the difference in temporal binding across Agency and No Agency conditions reduced as schizotypy levels increased.

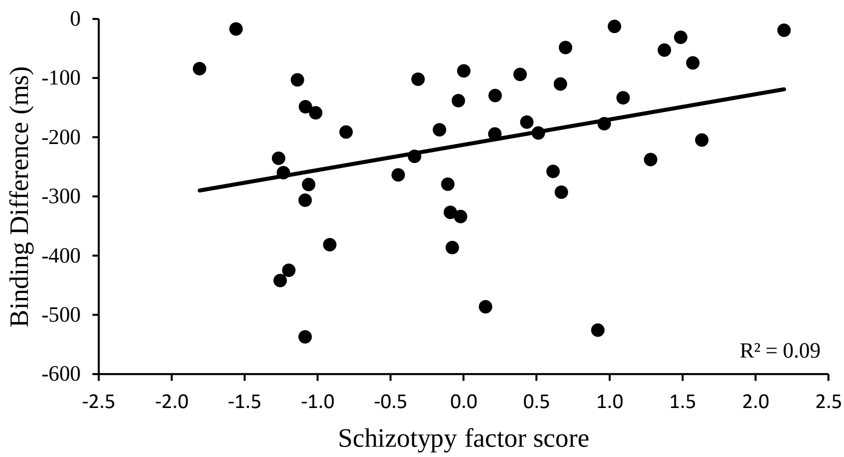

Figure 27. The significant relationship between Schizotypy and Binding Difference score in females, *r* = .31.

Discussion

The data in Experiment 6a investigates the role of schizotypy on temporal binding in females. In general, the data indicate binding effects whereby temporal binding is greater under Agency conditions compared with No Agency conditions. Of particular interest was the effect of individual levels of schizotypy on temporal binding, an implicit measure of agency, during Agency and No Agency tasks. Unlike in Dewey and Knoblich (2014), the findings here show that temporal binding is somewhat abnormal for those with high levels of schizotypy. The degree of temporal binding for Agency and No Agency conditions was not modulated by Low and High levels of schizotypy (note the significant interaction, but non-significant contrast analysis for the CAPS scale). However, interestingly, the Binding difference, i.e. the differentiation of temporal binding between Agency and No Agency tasks, is reduced for those with high levels of schizotypy, such that they produce more similar temporal binding across Agency and No Agency conditions, compared with individuals with low schizotypy scores. It must be noted however that these effects are not consistent across all schizotypy measures, only for the CAPS measure. Furthermore, the difference in temporal binding across the Presence of Agency manipulation was correlated with scores on the schizotypy measures, for which a positive relationship between Binding Difference scores and levels of schizotypy was observed for the SPQ-B and CAPS scales (note that the alpha value was *p* = .050 for this analysis using the CAPS measure). This effect was further confirmed by reducing the schizotypy measures to one variable using PCA. This relationship was non-significant using the SMSS schizotypy scale. These findings are similar to those found in Haggard et al. (2003) who investigated the sense of agency using the Libet clock method with patients with schizophrenia and found an effect of enhanced temporal binding between two action unrelated events compared with healthy controls in addition to the hyper-binding effect for action-related conditions.

The data analysed here was comprised only of female participants. The prevalence of schizophrenia however, is stronger in males, and so the effects observed here, using a subclinical population, may be stronger with a male sample. Experiment 6b therefore examines the role of individual differences in subclinical levels of schizotypy on the implicit measure of agency in males.

Experiment 6b

Experiment 6b aimed to investigate the effects of individual differences in schizotypy on the measure of implicit agency in males, and is therefore a direct replication of experiment 6a, with the exception of the gender of the sample. In Experiment 6a an effect was observed whereby individuals with high levels of schizotypy demonstrated a reduced binding difference score compared with those with low levels of schizotypy. This reflects the reduction in temporally distinguishing between an event and its causal action, and two action-unrelated events. It is believed that this effect would be stronger in males due to the higher prevalence of schizophrenia in this population. An increased disruptive effect of temporal binding, would therefore be expected in the current experiment.

Method

Participants

Fifty-four males were recruited from the University of East Anglia, across two separate data collection stages. The males were aged 18 – 37 years (*M* = 22.3, *SD* = 5.01) and completed the experiment in return for payment or course credit. Participants gave informed consent and were naïve as to the nature of the experiment. Exclusion criteria were the same as in Experiment 6a, for which data from 11 participants were removed (therefore, N = 43).

Materials, apparatus and stimuli

Experiment 6b used the same material, apparatus and stimuli as in Experiment 6a.

Design and procedure

The design and procedure was the same as in Experiment 6a with the exception that during the second stage of data collection participants completed the Presence of Agency manipulation as part of a 45 minute experimental session alongside one of the two original additional experimental tasks. The mean length of the jittered stimulus interval was comparable across the Agency and No Agency conditions, t = .46, p = .65. As in Experiment 6a the additional task was run for data collection of an unrelated research questions for other researchers and so are not further discussed.

As in Experiment 6a, participants were allocated to either a Low or High Schizotypy Group separately for each scale, determined by lower and upper third scores, inclusive of equal scores. For the SPQ-B scale the Low Schizotypy Group was therefore comprised of 15 participants with scores from 0-5, and the High Schizotypy Group was comprised of 17 participants with scores from 8-18. For the CAPS scale the Low Schizotypy Group was comprised of 19 participants with scores from 0-2, and the High Schizotypy Group was comprised of 14 participants with scores from 4-15. For the SMSS scale the Low Schizotypy Group was comprised of 13 participants with scores from 2-7, and the High Schizotypy Group was comprised of 14 participants with scores from 13-24. The final samples for the analyses using participants in the upper and lower thirds of the scales are therefore as follows: SPQ-B: N = 32; CAPS: N = 33; SMSS: N = 27.

Results

Data from five participants were removed for not carrying out the temporal binding task as required, resulting in a final sample size of 38. Individuals' average reproduction error across Agency conditions were additionally screened for mean values which exceeded +/- 3 *SD* from the group mean for which no participants were further removed.

Schizotypy scores

As in Experiment 6a, average scores were calculated for each of the schizotypy scales. For SPQ-B the average score (out of 22) was M = 7.3, SD = 4.39, which is below the general average (Raine & Benishay, 1995; M = 9.5, SD = 5.3). For CAPS the average score (out of 32) was M = 3.48 SD = 3.39, which is below the average (M = 7.3, SD = 5.8; Bell et al. 2005). Finally, for SMSS our average score (out of 42) was M = 11.81, SD = 6.09, which is higher than the average score (M = 8.4, SD not available; calculated from Mason & Claridge, 2006). The scores on the schizotypy scales did not significantly differ across gender: SPQ, $t(80) = -1.68$, $p = .097$, $d_z = .19$; CAPS, $t(80) = .91$, $p = .365$, $d_z = .1$; SMSS, $t(80) = -.559$, $p = .578$, $d_z = .06$.

Reproduction errors

Trials with reproduction errors which exceeded +/- 3 *SD* from the mean were removed (0.28% of trials). Reproduction error data were analysed using a paired samples *t* test revealing that in Agency conditions mean reproduction error was greater compared to in No Agency conditions, $t(37) = -8.98$, $p < .001$, $d_z = 1.46$ (*M* = -207ms, SD = 295, and *M* = 24ms, *SD* = 327, respectively). This indicates that the agency manipulation was successful.

As in Experiment 6a, three 2 x 2 ANOVAs were run with the factors Presence of Agency and Schizotypy Group. The result of the three 2 x 2 ANOVAs (see Table 3) revealed main effects of Presence of Agency for all three schizotypy scales, whereby temporal binding was greater under conditions of Agency compared to No Agency: SPQ-B: $F(1, 30) = 65.2$, $p < .001$, $\eta p^2 = .68$; CAPS: $F(1, 31) = 96.37$, $p < .001$, $\eta p^2 = .76$; and SMSS: $F(1, 25) = 61.04$, $p < .001$, $\eta p^2 = .72$. The interaction was non-significant across all three scales: SPQ-B: $F(1, 30) = .22$, $p = .64$, $\eta p^2 = .007$; CAPS: $F(1, 31) = 2.36$, $p = .134$, $\eta p^2 = .071$; and SMSS: $F(1, 25) = .28$, $p = .61$, $\eta p^2 = .01$.

Table 3

Male data reproduction error across the factors Presence of Agency and Schizotypy Group for the SPQ-B, CAPS and SMSS measures of schizotypy.

		Reproduction Error (ms)	
		Agency *M (SD)*	No Agency *M (SD)*
SPQ-B	Low Schizotypy	-174 (354)	50 (374)
	High Schizotypy	-214 (292)	38 (261)
CAPS	Low Schizotypy	-202 (268)	-29 (233)
	High Schizotypy	-265 (324)	-28 (392)
SMSS	Low Schizotypy	-174 (295)	22 (270)
	High Schizotypy	-207 (293)	17 (327)

A further three contrasts (see Figure 28) revealed that the Binding Difference scores, although notably trending in a direction opposite to that in Experiment 6a, were not significantly different across Low and High Schizotypy Groups for any of the three scales: SPQ-B: $t(30) = .47$, $p = .64$, $d_z = .08$; CAPS: $t(31) = 1.54$, $p = .134$, $d_z = .02$; SMSS: $t(25) = -.52$, $p = .61$, $d_z = .1$.

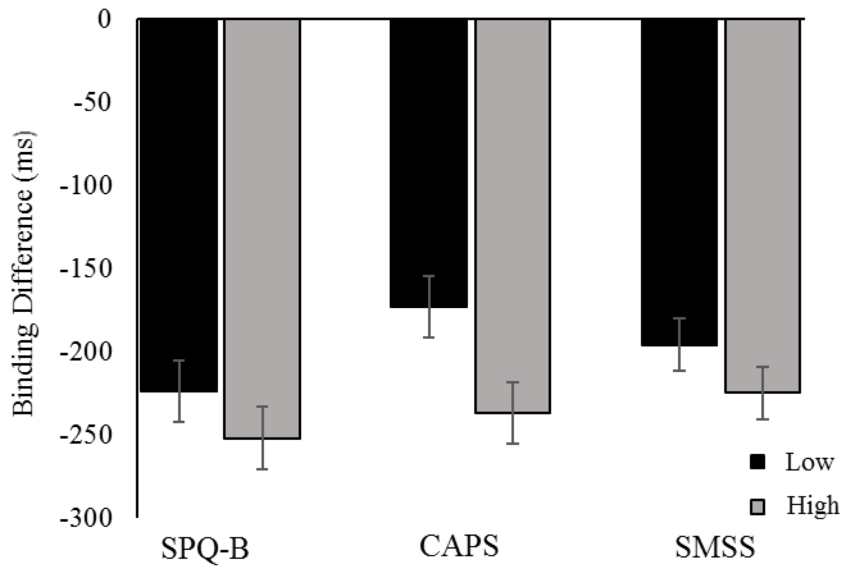

Figure 28. Binding Difference scores across High and Low Schizotypy Groups for the three measures of schizotypy, SPQ-B, CAPS and SMSS. The contrasts revealed non-significant effects for all three measure of schizotypy.

Like in Experiment 6a, the role of levels of schizotypy on temporal binding was examined using Pearson's *r* correlations between Binding Difference scores and the schizotypy scales on the full sample. Unlike in Experiment 6a, whereby significant correlations were observed between SPQ-B and CAPS and Binding Difference scores, none of the correlations between Binding Difference scores and the schizotypy scales were significant (see Figures 29, 30 & 31): SPQ-B: $r\ (36) = .054$, $p = .749$; CAPS: $r\ (36) = -.057$, $p = .732$; SMSS: $r\ (36) = -.103$, $p = .54$. The correlation coefficients for the correlation between Binding Difference scores and SPQ-B in females ($r = .297$) and males ($r = .054$) do not significantly differ from each other ($z = 1.1$, $p = .27$). The correlation coefficients for the correlation between Binding Difference scores and CAPS in females ($r =.37$) and males ($r = -.057$) marginally significantly differ from each other ($z = 1.94$, $p = .052$).

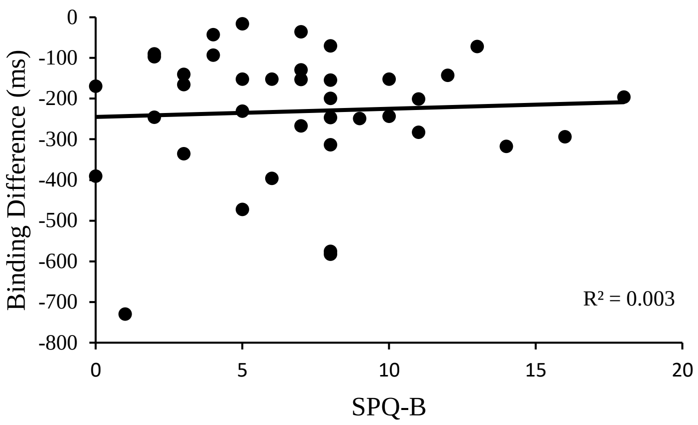

Figure 29. The non-significant relationship between SPQ-B and Binding Difference scores in males, *r* = .054.

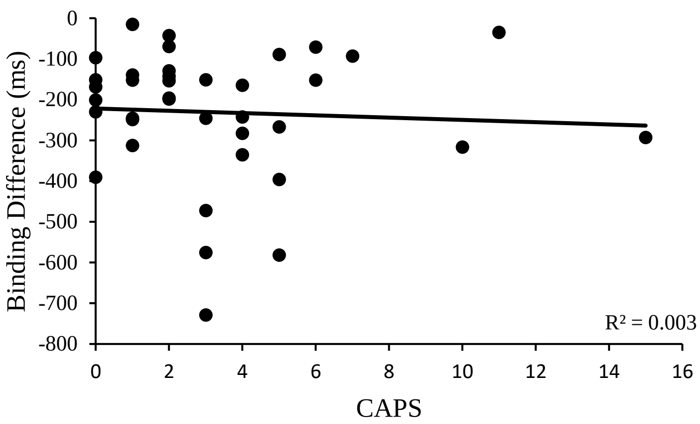

Figure 30. The non-significant relationship between CAPS and Binding Difference scores in males, *r* = -.057

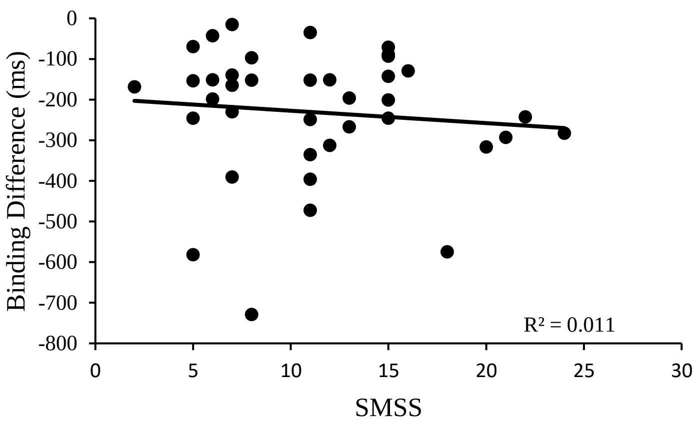

Figure 31. The non-significant relationship between SMSS and Binding Difference scores in males, *r* = -.103

Like for the female data, a PCA was run on the total scores of three measures of schizotypy (SPQ-B, SMSS and CAPS) to give one overall ‘Schizotypy’ variable. This analysis was run on the full male sample, N = 38. The suitability of PCA was assessed prior to analysis. Inspection of the correlation matrix showed that all variables had at least one correlation coefficient greater than 0.3. The overall Kaiser-Meyer-Olkin (KMO) measure was acceptable at 0.66 with individual KMO measures all greater than 0.61. According to Kaiser (1974), the individual KMO measures observed here are classified as ‘mediocre’ to ‘middling’. Bartlett's Test of Sphericity was statistically significant ($p < .001$), indicating that the data was likely factorisable.

PCA revealed one component, the factor ‘Schizotypy’, that had an eigenvalue greater than one, explaining 67.5% of the total variance. The component loadings and respective proportion of variance accounted for by each scale are as follows: SPQ-B: .82, 67%; SMSS: .87, 76%; and CAPS: .77, 59%.

The relationship between the factors scores of this new Schizotypy factor and Binding Difference was examined, revealing a non-significant relationship, r (36) = -.044, p = .79, presented in figure 32.

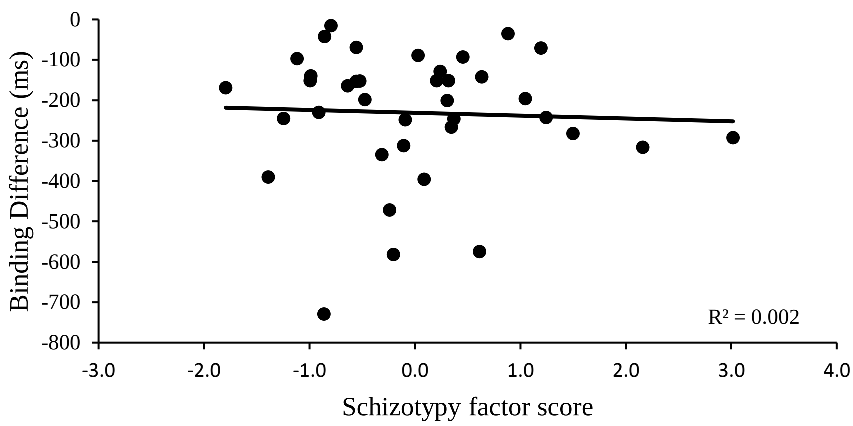

Figure 32. The non-significant relationship between Schizotypy and Binding Difference score in males, r = -.044.

Discussion

Experiment 6b investigated the role of individual differences in levels of schizotypy on the implicit measure of the sense of agency, temporal binding, in a male population. Experiment 6b therefore was a direct replication of Experiment 6a except for the gender of the sample. Experiment 6a provided some evidence for disruptions to binding difference scores for individuals that had high levels of schizotypy. Because the prevalence of schizophrenia is reportedly higher in males, it was believed that a male sample may provide a stronger and more consistent disrupted binding difference effect.

The data in Experiment 6b demonstrated the expected general binding effects whereby temporal binding was greater under conditions of agency compared to conditions absent of agency. However, unexpectedly there was no effect of levels of schizotypy on the degree of temporal binding and binding difference scores, neither for individual schizotypy measures, nor when these measures were reduced to one.

General Discussion

The current study investigates the effect of individual levels of schizotypy in a healthy population on the implicit sense of agency, measured using an interval reproduction paradigm. Due to gender differences in the prevalence and symptomology of schizophrenia the female and male sample was analysed separately (Experiment 6a and 6b, respectively). The effects of schizotypy levels on the implicit measure of agency was also measured using standardised schizotypy scales that are believed to measure schizophrenia like traits in the typical population. The scales used were SPQ-B, CAPS and SMSS (Bell et al., 2006; Mason et al., 2005; Raine & Benishay, 1995).

Overall, the data indicate large agency effects (Experiment 6a: $d_z = 1.53$; Experiment 6b: $d_z = 1.56$) in that when outcomes were preceded by an action (button press) there was greater temporal binding, compared to when events had no agentive cause (two beeps). These findings replicate previous investigations examining agency using this implicit measure of temporal binding (Beuhner & Humphreys, 2009; Dewey & Knoblich, 2014; Engbert et al., 2007; Engbert & Wohlschläger, 2007; Haggard et al., 2002; Humphreys & Beuhner, 2010; Poonian & Cunnington, 2013).

Previous research shows that individuals with schizophrenia demonstrate a disrupted sense of agency, and this manifests as hyper-binding in temporal binding paradigms. This hyper-binding refers to enhanced temporal binding under conditions of agency. The pattern of data in both the female and male sample however failed to replicate these results in this subclinical sample, showing that there was no effect of the levels of schizotypy on the degree of temporal binding across conditions both present and absent of agency.

Binding difference scores were additionally calculated to determine the relationship between the implicit measure of agency and schizotypy scores. Binding difference scores refer to the difference in binding effects between agency and no agency conditions such that a binding difference score below zero reflects greater temporal binding in agency compared to no agency conditions. This binding difference score was examined across levels of schizotypy. In females there was limited evidence (a significant effect using the CAPS measure and non-significant trends for the SPQ-B and SMSS measures) that binding difference was reduced for those with higher levels of schizotypy compared with those with lower levels of schizotypy, the effect size of this finding was medium, $d_z = .51$. This effect is further supported by two medium sized effects whereby as schizotypy scores increased the binding difference score reduced when using the SPQ-B and CAPS measures ($r = .297$, and $r = .37$, respectively; note that the analysis for the SPQ-B measure reached significant at $p = .050$, for future replications may aim to increase the sample size to determine a robust effect). This effect was non-significant when using the SMSS measure of schizotypy, but was further confirmed when the three schizotypy scales were reduced to one measure of schizotypy using PCA. This effect is reflective of those reporting greater schizophrenia like traits temporally differentiating less between the conditions present and absent of agency. In males, there were no effects observed for the effect of levels of schizotypy on the difference in temporal binding across agency and no agency conditions. Note, however, that for the PCA analysis of the female sample the overall KMO measure fell just below the acceptable levels (0.57 here where the desired is 0.6), and that the individual KMO levels are classified as ‘miserable’ (Kaiser, 1974). These results should therefore be interpreted with caution and further research should aim to confirm these effects with a larger sample.

Although there were non-significant effects of binding difference scores across High and Low schizotypy groups in males, and only one scale that showed this effect in females, it should be noted that the trend of the data goes in the opposite way across the males and females. Whereas in the female data High Schizotypy groups showed lesser binding difference than Low Schizotypy groups, in males this trend of the pattern of data was reversed, the High Schizotypy groups shower greater binding difference than the Low Schizotypy groups. The relationship between binding difference and levels of schizotypy was also however non-significant in males, and significant only for two measures in females. This trend in the data can be further examined in future research using a larger or clinical sample.

The patterns of data found in Experiments 6a and 6b therefore demonstrate no role of schizotypy for temporal binding in males, and in females limited evidence for this effect. In females, this effect is such that levels of schizotypy do not modulate towards hyper-binding neither specific to Agency conditions as previous research reports, nor for action-unrelated events. Instead, what is found here in what is believed to be the first instance of a disruption in the implicit temporal binding measure of agency, in which the ability to temporally distinguish between an action and the outcome, and two action-unrelated events, functions dependent on the individual levels of schizotypy. Whereby, greater levels of schizotypy like traits result in a reduced temporal differentiation between agency and no agency conditions.

Mechanisms for reduced differentiation in binding difference

Experiment 6 offers some evidence that females with high levels of schizotypy demonstrate more comparable temporal reproductions across conditions of agency and no agency compared with those with low levels of schizotypy. Despite evidence for underestimations in time perception in schizophrenia, the pattern of data observed here cannot be accountable to additive time perception deficits because there was no main effect of levels of schizotypy on the degree of temporal binding. Instead, these data may reflect the reduced ability of the mechanism which distinguishes temporally between events as a consequence to our own actions, and two action-unrelated events.

The pattern of data here shows that the comparability of temporal binding between events under agency and no agency conditions is modulated by levels of schizotypy, such that high schizotypy levels are associated with less difference in temporal binding between agency and no agency conditions. This is similar to findings of temporal binding for sequential tones in Haggard et al., (2003), although binding difference was not directly investigated here.

The optimal cue integration account of agency proposes that agency is generated using a variety of predictive, postdictive and top-down processing cues. As previously discussed, the predictive motor cues are dysfunctional in schizophrenia and for those with high levels of schizotypy. When the reliability of sensorimotor predictions decrease, the influence of external cues increases (Moore & Haggard, 2008; Synofzik et al., 2013). In schizophrenia, however, the influence of external cues may mislead agency attribution as they themselves are less reliable because they are interpreted with exaggerated meaning (Frith, 1994; Synofzik et al., 2013). To explain the ‘reduced differentiation’ effect found here in the female sample it is proposed that the unreliability of predictive motor cues may result in such cues never being considered, even under conditions void of action, such as in the no agency conditions here. Post-dictive cues may therefore be more relied upon using retrospective factors of the action outcome to infer agency.

Indeed, as previously mentioned, it has been found that in healthy participants the higher the probability of an outcome to an action, the greater the temporal binding, even when the outcome did not occur (Haggard & Moore, 2008). However, in patients with schizophrenia, even in highly probable conditions that an outcome would occur after an action, temporal binding only occurred when the outcome was present (Voss et al., 2010). This demonstrates the importance of the influential role of action *outcomes,* or sensory events, in schizophrenia, and also shows how sensorimotor signals of the action are dismissed in the construction of implicit sense of agency.

Moreover, the reduced temporal differentiation between events in agency and no agency conditions may reflect a tendency for individuals with high levels of schizotypy to dismiss the role of sensorimotor cues altogether. Instead, factors such as causality, contiguity and contingency between two events in the generation of temporal binding may be relied upon to create the sense of agency (Beuhner & Humpreys, 2009; Humphreys & Beuhner, 2010). This bias of self-relevance to causally related sequential stimuli may be a result of the abnormally enhanced salience of stimuli at neural levels (Ford & Mathalon, 2004; Ford, Gray, Faustman, Roach & Mathalon, 2007; Oestreich, Mifsud, Ford, Roach, Mathalon & Whitford, 2015). This can explain some symptoms in schizophrenia such as delusions of reference whereby the individual experiences self-relevance for events in the world which are mere coincidences, events that in actuality have no significance to them, and are not a result of an action.

The patterns of data here do not show the expected effect of hyper-binding during Agency conditions under high levels of schizotypy. Studies using clinical samples report this hyper-binding effect (Haggard et al., 2003; Voss, et al., 2010), whereas another study investigating the role of schizotypy, similarly to the current experiment, did not find an effect on the sense of agency (Dewey & Knoblich, 2014). Hyper-binding observed in clinical samples is believed to be a result of a dysfunctional forward prediction model (Blakemore et al., 2001; Blakemore et al., 2002; Koreki et al., 2015), captured, for instance, by the ability for individuals with schizophrenia to tickle themselves (Blakemore et al., 1999; Blakemore et al., 2000). It is therefore possible that the lack of hyper-binding in the current study may be a result of hyper-binding being an effect specific to clinical levels of schizophrenia, rather than subclinical-like traits. Further research can elucidate this notion by investigating temporal binding across the full continuum of schizophrenia, from subclinical traits, to disease, to determine the relationship with how events are distinguished temporally across conditions present and absent of agency.

Addressing gender differences

The data here provide limited evidence for the disruptive effect of levels of schizotypy on the implicit measure of agency in females, however this effect was not consistent in males. The gender differences observed here may be due to differences in the schizotypy like traits across genders. For individuals with schizophrenia, positive and affective symptoms are much more prevalent in females compared to in males (Häfner, 2003; Ochoa, et al., 2012). This may explain the pattern of data here since positive symptoms are associated with FRS and disruptions with the self. However, for the current data the extent of positive schizotypic symptoms was not measured. The scores on each of the scales also did not significantly differ across gender, leading to the possibility of an alternative explanation for the gender differences observed here. For instance, females sustain more attention to interval duration tasks and have better memory of perceived temporal judgements than males (Block, Hancock & Zakay, 2000). This may suggest that the failure to detect a significant relationship between schizotypy and temporal binding differences in males may be due to the inability to perform the interval reproduction task with accuracy.

Limitations, applications and future research

The reduced temporal differentiation across agency and no agency conditions in females was observed only for the CAPS (contrasts and correlation) and SPQ-B (correlation only) measures of schizotypy. Although all three scales are valid for measuring schizotypy traits, there is some variation across these measures as to the specific traits that they assess. For instance, the SPQ-B measures cognitive-perceptual deficits, interpersonal deficits and disorganisation; The CAPS measures clinical psychosis, temporal lobe disturbance and chemosensation; and the SMSS measures unusual experiences, cognitive disorganisation, introvertive anhedonia and impulsive nonconformity. It is not clear as to why the SPQ-B and CAPS measures generated the effects observed here, where as the SMSS did not. However, it can be proposed that the subscales were more sensitive to identifying traits responsible for the temporal dysfunction observed here in the SPQ-B and CAPS measures. Further research can focus on specific traits accounted for not only by the measures used in the current study, but also using alternative measures of schizotypy, in order to highlight the factors underlying the role of schizotypy for agency attribution.

The current investigation found gender differences in the modulatory role of schizotypy on temporal binding. Although there is some evidence for differences in symptomology of schizophrenia across gender which could explain these effects, the current measures were not able to examine the role of differences in schizophrenia like traits. Furthermore, scores on the schizotypy scales did not significantly differ across gender. Of particular interest would be the investigation of the relationship between delusions of inference, to examine the role of temporal binding for those who find causality in coincidences. It is therefore proposed that further research takes a more in depth examination into the role of positive and negative schizophrenia like traits on implicit measures of agency, in addition to measuring gender differences in states of attention and task focus, which, as discussed, may also account for some differences in gender observed here.

Previous research into the role of schizotypy and schizophrenia on a sense of agency has focused on motor prediction errors as the cause for deficits in the sense of agency. The data here however, reveal an interesting effect of temporal binding between two action-unrelated events. This effect was also found for those with schizophrenia using the Libet clock method (Haggard et al., 2003), however, although evidence indirectly supports the role of temporal binding for sequential events absent of action, manipulations to directly test this account are needed. Further examination may also include the transference of the interval reproduction paradigm for use with patients with schizophrenia, to determine whether this effect is present in patients with the disease. Investigation into the factors that contribute to this effect may also elucidate the role of temporal binding for the sense of agency in schizophrenia, such as predictability and temporal proximity.

The deficits in self-relevance to events for which there is no self-significance highlighted here by the current data can explain positive symptoms of schizophrenia such as delusion of control, auditory hallucinations, passivity and delusions of reference. Although there is a long route of empirical investigation to engage in to fully understand the means, depths and causes of these effects found here, research into schizotypy and its role on implicit measures of agency offer themselves to be starting points with which to understand the symptoms of schizophrenia. After such understanding can interventions and therapies be aimed at remedying such deficits.

The role of agency attribution in schizophrenia has received much empirical examination, however, the atypical ascription of agency is also prevalent in other disorders (Moore, 2016). Alien hand syndrome, anosognosia for hemiplegia and obsessive compulsive disorder can be regarded as disorders of agency. These disorders can also benefit from the understanding of agency errors in schizophrenia, however, further examination of this directly involving the disorders may prove to ameliorate understanding of agency deficits within and across disorders.

Conclusion

Experiments 6a and 6b investigated the modulatory role of levels of schizotypy on an implicit measure of the sense of agency, temporal binding. Again, the general effect of temporal binding was observed under conditions of agency compared to no agency. In females, a negative relationship between levels of schizotypy, measured using CAPs and SPQ-B scales, and the degree of difference in temporal binding across conditions was observed. In particular, females with high levels of schizotypy demonstrated a smaller binding difference, and so temporally distinguished less between agency and no agency conditions, compared with females with low levels of schizotypy. This effect is believed to be driven by errors in motor prediction which mean that these internal cues are not reliable, in addition to a general tendency for individuals high in schizotypy to create a self-relevance to events that allude to sequential causality, which may cue towards self-agency. These results, for the first time, highlight the role of general hyper-binding across both action-related and action-unrelated events. The findings here can therefore help to enlighten causes for delusions of inference symptoms in schizophrenia and provide further support for temporal binding being sensitive to elements of cognitive processing such that temporal binding is not confined to action. Moreover, individual levels of schizotypy offer one context in which unreliable external cues are relied upon over motor and sensory cues, resulting in the generation of a disrupted sense of agency.

Chapter 7: The role of valence and gaze orientation of faces for the implicit sense of agency.

As previously discussed in Chapter 2, there is a bidirectional relationship between emotional states and actions. For instance, interactions in the world can result in emotional states such as pride or guilt, and emotional states such as pride or guilt can motivate further recreation or aversion of the behaviour (Gentsch & Synofzik, 2014). The intimate link between actions and affect are in particular visible in affective disorders, whereby depression can be comprised of symptoms of anhedonia, passivity, helplessness, incapacity, diminished volition, and fewer interactions with the external world (Ratcliff, 2013). Depressive moods induced into healthy participants similarly reduce the degree of agency over actions (Obhi et al., 2013). It is believed that reductions in agency observed in affective disorders may be due to a lack of responsiveness to reward resulting in the inability to incorporate the behaviour with the self (Vrieze et al., 2013).

Individuals have a bias towards positive stimuli, for instance, our pointing actions are perceived as being closer to positive rather than negative stimuli (Wilke et al., 2012). This is known as a self-serving bias whereby positive events are attributed to the self, and negative events are attributed to external factors. It is believed that the function of the self-serving bias is to maintain a healthy self-esteem (Greenberg et al., 1982, Mezulis et al., 2004), but it may also act as a link between actions, agency and emotions. For instance, the degree of the sense of agency attributed to the self for a given action outcome may serve as a mechanism which modulates the self-serving bias. Indeed the implicit temporal binding measure of agency is found to be reduced for negative events, such as monetary losses, compared with positive events, such as monetary gains (Takahata et al., 2012).

Recently, attention has been given to the role of outcomes to actions which are positively or negatively valenced. For instance, Yoshie and Haggard (2013) investigated the role of the valence of social emotional sound responses to actions. Using the Libet clock method to implicitly measure agency, in a blocked design participants' keypress actions were followed by either positive, such as amusement and achievement, or negative emotional vocalisations, such as fear and disgust, or neutral tones. The authors found that temporal binding was reduced in conditions of negative outcomes, compared with positive and neutral outcomes. The pattern of data here support the notion of self-preservation through the self-serving bias, whereby negative events are dissociated from the self. It was also suggested that the temporal rejection of negative outcomes may act as a mechanism to facilitate future social interactions with positive consequences and avoid acts with negative outcomes (Yoshie & Haggard, 2013).

Christensen et al. (2016) also investigated the role of valenced social sounds on the implicit measure of agency, further examining the role of predictive and retrospective components of agency. Under conditions similar to Yoshie and Haggard (2013), whereby the valenced auditory outcomes were predictable, Christensen et al. found a different pattern of results. Rather than reduced binding for negative effects, they found comparable temporal binding for positive and negative action outcomes. Instead, reduced temporal binding was observed for neutral sounds. Moreover, when the occurrence of the sounds was not predictable, positive responses to actions enhanced temporal binding but only compared to neutral sounds. Again, the degree of temporal binding did not differ across positive and negative valence for non-predictable stimuli. Christensen et al's. data therefore indicated that neither predictive nor retrospective components of agency differentiated between the valence of social responses to actions.

Moreover, some indirect studies examining socially negative outcomes find results divergent to those of Yoshie & Haggard (2013). Moretto et al. (2011) investigated moral actions and the severity of the outcome and found that socially relevant moral conditions did not modulate the implicit measure of agency differently than economic – non-social – contexts. Interestingly, the increased negative severity of the action outcome, regardless of social relevance of the context, resulted in increased temporal binding as opposed to decreased temporal binding like in Yoshie and Haggard. The literature regarding the socially valent outcomes and the ascription of agency is therefore inconclusive. The current experimental chapter therefore aims to clarify the role of social outcomes to actions for the modulation of the sense of agency.

It is not clear why the results of Yoshie and Haggard (2013), Christensen et al. (2016) and Moretto et al. (2011) are so divergent. The experiment in these studies all examined the sense of agency using an implicit temporal binding measure, operationalised using the Libet clock method. What was not considered however, was the role of individual differences in how the stimuli were interpreted and the degree to which they were self-relevant. The affective coding of agency model (Gentsch & Synofzik, 2014) proposes that the emotional salience of stimuli can influence assessments of agency, however, differences in affective style, such as tolerance, emotion regulation and affect suppression, can mediate the effect of the stimuli on agency. This modulating role of affective style may therefore provide one reason for the divergent findings regarding the effects of socially valent stimuli on agency in the literature so far. The stimuli used in the studies were also either auditory stimuli (Christensen et al., 2016; Yoshie & Haggard,

2013) or moral dilemma scenarios (Moretto et al., 2011). It is also considered that the use of these types of stimuli may reduce the association of the outcomes to the self, especially since these moral dilemmas and auditory-alone interactions can be thought as not typically reflecting everyday social interactions. To overcome these, what *may* be, confounding factors the following three experiments investigate the role of socially valent outcomes and individual differences in social anxiety and empathy on the sense of agency.

Due to its role as an implicit measure of agency, considerations should be taken for the effects of stimuli valence on the subjective time perceived between two events. Findings tend to consistently find that negative stimuli increase subjective time. For example, sounds, faces and images of or evoking anger, sadness, fear and disgust all elongate subjective time compared with both neutral and positive stimuli (Bar-Haim et al., 2010; Doi & Shinohara, 2009; Droit-Volet et al., 2004; Droit-Volet et al., 2014; Gil & Droit-Volet, 2012; Grommet et al., 2011; Mella et al., 2011; Yamada & Kawabe, 2011).

Chapters 3 and 4 highlight the role of cognitive resources for the ascription of the sense of agency, whereby when resources are diverted away from processing the cues for agency the implicit measure of agency, temporal binding, is reduced. It is therefore important to consider the role of attentional capture of valenced stimuli given the research questions for the current experimental chapter. Indeed, the human perceptual system is biased to attend towards visually threatening or fear inducing events (Maratos, 2011; Vuilleumier & Huang, 2009). This bias is facilitated by neural circuitry specific to the processing of threat stimuli (Vuilleumier, 2005). Threatening stimuli, such as angry faces, also capture or hold attention to a greater extent than positive or neutral stimuli, a process which consumes cognitive resources (Maratos, 2011; Peers & Lawrence, 2009; Peers, Simons & Lawrence, 2013).

Moreover, appraisal processing theories propose that gaze direction and facial expressions together provide socially rich information about mental states in the face, and the direction in which this mental state is focused (Sander, Grafman & Zalla, 2003; Sander, Grandjean, Kaiser, Wehrle & Scherer, 2007). From the combination of facial affect and gaze direction the looker's affect can therefore be interpreted with regards to the relevance to the self (N'Diaye, Sander & Vuilleumier, 2009). For instance, the self-relevance of fearful faces is greater when gaze is averted, whereas self-relevance for angry faces is greatest for direct gaze. The nature of self-relevance may also play a crucial role in how agentic one may feel over an action followed by a facial expression of varying gaze orientations. For instance, one may expect that an action followed by a negative self-relevant facial expression such as anger or disgust, may be interpreted as being more agentically relevant if the gaze orientation is direct.

Gaze orientation of emotional stimuli have further implications for attentional resources. Direct gaze captures attention more than averted gaze when the facial stimuli show a negative self-referent response (Ricciardelli, Iani, Lugli, Pellicano & Nicoletti, 2012; Ricciardelli, Lugli, Pellicano, Iani, & Nicoletti, 2016). In such cases, in accordance with the resource limitation account for disruptions to the ascription of agency (see Chapters 3 & 4), it could be expected that sense of agency may be reduced.

Facial expressions and gaze orientation offer strong clues as to the mental state of the face and whether a positive or negative event has occurred. There are however, individual differences in how facial expressions are processed, which may offer an explanation as to the divergent findings for the effect of action-outcome valence on the sense of agency (Gentsch & Synofzik, 2014). For instance, differences in personality, oxytocin and testosterone modulate the processing of emotional faces (Groppe et al., 2013; Honk, Schutter, Bos, Kruijt, Lentjes & Baron-Cohen, 2010). The disruptive effect of emotional face processing is further demonstrated by individuals with anxiety disorders. For instance, compared with low social anxiety, those with high social anxiety focus more on threatening stimuli, negative emotional faces and negative social-evaluative words and less on positive stimuli (Frewen, Dozois, Joanisse & Neufeld, 2008; Mansell Ehlers, Clark & Chen, 2002; Mogg, Philippot & Bradley, 2004; Thoern, Grueschow, Ehlert, Ruff & Kleim, 2016; Pishyar, Harris & Menzies, 2004). Individuals with social anxiety also show sensitivities to the direction of eye gaze. For instance, the perception of gaze direction is biased such that individuals with anxiety have an enhanced experience of self-directed gaze (Gamer, Hecht, Seipp & Hiller, 2011; Harbort, Philippot & Bradey, 2013). Moreover, the enhanced experience of self-directed gaze was also correlated with the degree of social anxiety when the looking faces were negative (Schulze, Renneberg & Lobmaier, 2013). Individual differences in social anxiety may therefore modulate the degree of agency measured over social emotional outcomes. This effect may be driven by depleted attentional resources to the agency task, which would manifest as reduced temporal binding. Alternatively, this effect may be driven by an increased self-relevance of the social outcomes, which would show as increased temporal binding.

To provide evidence that can help to establish the role of the valence of social emotional outcomes to actions for the ascription of the sense of agency, three experiments were conducted to examine the roles of facial expression valence, gaze orientation and individual differences in social anxiety on an implicit measure of agency.

The experimental focus of Chapter 7

As discussed, social emotional valence, gaze orientation and individual differences in social anxiety may have influential roles on how an individual perceives events as being associated with the self. However, despite substantial investigation into these factors in areas of time perception and attention, they have not yet been investigated for their modulatory effects on the implicit sense of agency. A few studies do investigate the role of socially relevant stimuli for the implicit sense of agency, for instance, using social emotional sounds (Christensen et al., 2016; Yoshie & Haggard, 2013) and socially moral scenarios (Moretto et al., 2011), but the data found in these studies offer mixed conclusions as to the role of socially valent outcomes on agency. Considering the potential for gaze orientations, facial expression valence and individual differences in social anxiety to modulate the degree of self-relevance and cognitive resources, these factors are examined for their effects on agency in the following three novel experiments. Experiment 7 focuses on happy and sad facial expressions with direct gaze. Experiment 8 examines the role of happy and disgust facial expressions across both direct and averted gaze. Finally, Experiment 9 examines the role of happy and disgust faces and dynamic gaze, whereby the gaze orientation moves from direct to averted gaze, or averted to direct gaze, during the trial. All three experiments measured the sense of agency implicitly using an interval reproduction method of temporal binding, whereas Yoshie and Haggard (2013), Christensen et al., (2016) and Moretto et al. (2011) used the Libet clock method.

Given the diminishing effect of attention for self-relevant negative stimuli, and the notion that the sense of agency provides a mechanism for the self-serving bias, it is predicted that positive social outcomes to actions will act as a cue for the generation of agency, strengthening the implicit measure of agency. It is further expected that negative social outcomes to actions will not be a cue for agency, weakening the implicit measure of agency. Social anxiety also shows enhanced sensitivities to gaze direction of negative stimuli, so it is further predicted that this effect will be modulated by levels of social anxiety. If high anxiety puts strain on cognitive resources the sense of agency can be expected to be reduced for negative stimuli. Alternatively, if high anxiety enhances the self-relevance to negative stimuli, this would act as a cue for agency, which will be expected to increase.

Experiment 7: The role of social responses on implicit sense of agency

Experiment 7 was designed to test the effects of social emotional responses to actions on the implicit sense of agency. Participants made temporal reproductions of intervals between their actions, a keypress, and the consequence, a socially valent facial expression. The socially valent facial expression was either positive (happy) or negative (sad). Levels of social anxiety were also assessed using the Social Phobia Inventory (SPIN; Connor, Davidson, Churchill, Sherwood, Weisler & Foa, 2000). If the implicit sense of agency is self-serving to attribute positive events with the self and to dissociate the self from negative events then agency would be increased for positive outcomes to actions, and decreased for negative outcomes for actions. This would be reflected with enhanced and attenuated temporal binding, respectively. It is also believed that this effect will be modulated by individual differences in social anxiety, such that if high social anxiety results in a self-reference to negative stimuli, individuals with high levels of social anxiety would show increased temporal binding to negative stimuli under agency conditions. However, if high social anxiety results in enhanced attentional capture for the negative stimulus, then individuals with high levels of social anxiety would show reduced temporal binding for negative stimuli in agency conditions.

Methods

Participants

Thirty-two Participants aged 18-20 years (*M* = 19, *SD* = 0.84; four were men) were recruited from the University of East Anglia. Participants completed the experiment in return for course credit or payment. Participants gave informed consent and were naïve to the research question. The study was approved by the School of Psychology Research Ethics Committee, University of East Anglia.

Apparatus and Stimuli

The Social Phobia Inventory Assessment (SPIN; Connor et al., 2000; Appendix 6) was administered. The SPIN is a 17 item questionnaire measuring fear, avoidance and physiological symptoms of social phobia. Each item is scored from 0-4, and item scores are totalled to give a score with a range of 0-68.

The Adult Empathy Quotient (EQ; Baron-Cohen & Cartwright, 2004; Appendix 7), a 40 item questionnaire measuring empathy, was also administered. Each item is scored from 0-2 with totalled item scores ranging from 0-80. The EQ did not show modulatory effects on temporal binding, and so is not further discussed.

Forty-eight images from the NimStim Face Stimulus set (Tottenham et al., 2009) were used to display neutral closed mouthed, happy open mouthed and sad closed mouthed facial expressions. Sixteen actors (eight male; actor numbers: 1, 2, 3, 6, 7, 8, 9, 10, 22, 23, 24, 25, 27, 28, 34 and 36) portrayed each of the three expressions (see Figure 33). Stimuli were presented in full colour on a white background using a BenQ monitor (size: 24 inches; resolution: 1920 x 1080 refresh rate: 60 Hz). A tone (150ms), 44Hz: created using Audacity® software) was presented using Sony 7506 headphones. Participants were tested in a group lab with up to four participants simultaneously tested at a time in booths with no access to each other during the task.

Figure 33. Examples of the facial expression stimuli used in Experiment 7. Model shown is number 1 of the NimStim face stimulus set (Tottenham et al., 2009) showing neutral, happy and sad facial expressions.

Design

In a 2 x 2 repeated measures design participants completed four experimental block types. Block types differed across two factors: Presence of Agency (Agency and No Agency) and Valence of facial expression (Happy and Sad). The dependent measure was the duration reproduction error. Reproduction error was calculated as the actual interval minus the reproduced interval. Levels of social phobia and empathy were also measured using the SPIN (Connor et al., 2000), and the EQ (Baron-Cohen & Cartwright, 2004) respectively. Temporal binding difference variables were also calculated for Happy faces (Happy Reproduction Error Differential: Agency Happy – No Agency Happy) and Sad faces (Sad Reproduction Error Differential: Agency Sad – No Agency

Sad). A negative Reproduction Error Differential reflects greater temporal binding in Agency conditions. Furthermore, a difference in reproduction error differential across happy and sad faces was also calculated (Valence Reproduction Error Differential; [Agency Happy – No Agency Happy] – [Agency Sad – No Agency Sad]).

Procedure

Presence of Agency manipulation. The presence of agency was manipulated using an Interval Reproduction task (Humphreys & Buehner, 2010; Poonian & Cunnington, 2013). Participants were presented with a neutral facial expression on screen. Participants were instructed that the facial expression of the facial stimulus on-screen would change from being neutral to either happy or sad after a first event. The first event was either a self-initiated spacebar press with their right hand index finger (Agency) or an auditory tone (No Agency, onset set at 500-1000ms after face stimuli onset). The stimulus interval was the delay between the first event and the point the facial expression changed and was selected at random (without immediate repeat) set at intervals of either 500, 750, 1000, 1250 or 1500ms. The valenced facial expression was presented for 1000ms. After a delay (jittered between 300 and 500ms) participants were presented with the instruction to 'Estimate' which promted participants to make response intervals, reproducing the delay they experienced between the first event and the facial expression change by depressing the spacebar with their right hand index finger for the duration they perceived the stimulus interval to have lasted (see Figure 34 for the Interval Reproduction task procedure and Valence manipulations for Experiment 7). The trial ended with a 1000ms fixation cross before the beginning of the next trial.

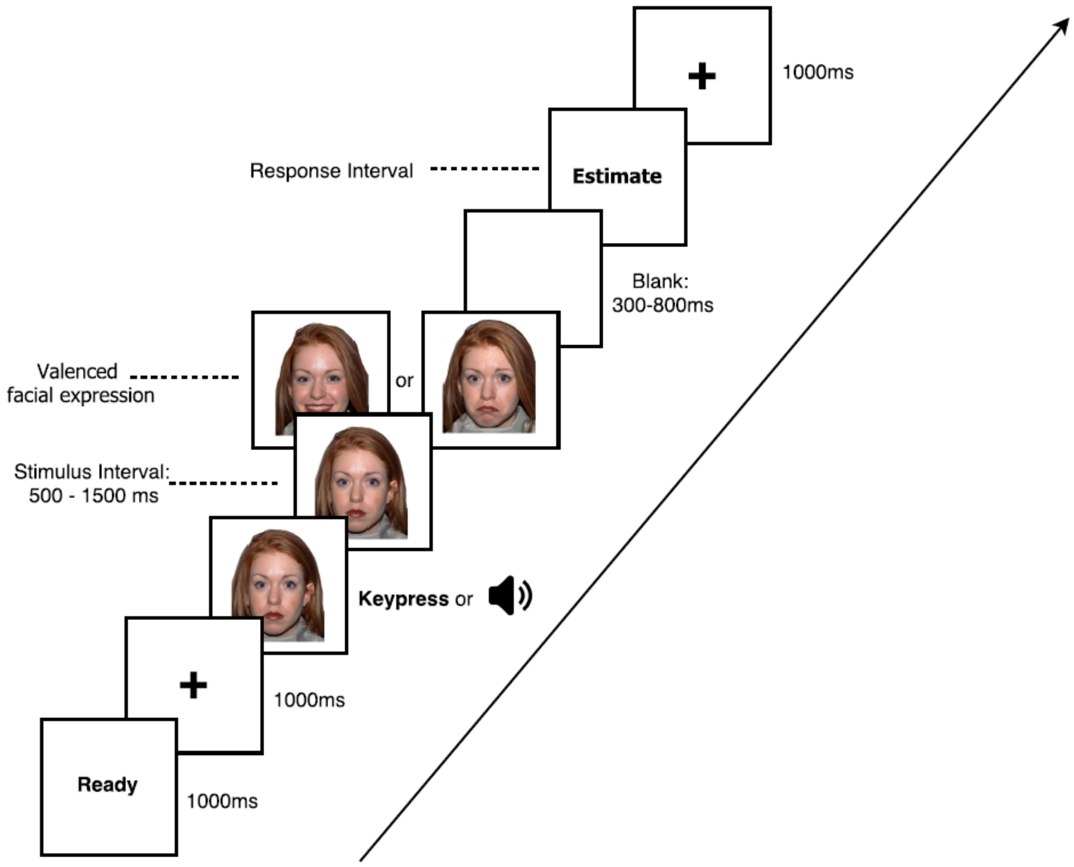

Figure 34. Procedure for the Interval Reproduction task in Experiment 7. In each condition participants were presented with a neutral face after which the first event occurred, either a key press (Agency) or a tone (No Agency). After a randomised stimulus interval (500-1500ms) the outcome, a valenced facial expression, either Happy or Sad, was presented. Participants were prompted to make response intervals by recreating the duration between the first event and the change in facial expression with the depression of the spacebar.

Before starting the experiment participants completed a short practice block involving the Presence of Agency and Valence manipulations. Each experimental condition consisted of 60 trials which were presented in three blocks, 20 trials per block. The experiment therefore consisted of 12 blocks. The order the scales (EQ and SPIN) and Interval Reproduction tasks was administered in was counterbalanced, as was the order the scales were administered. The order of blocks in the Interval Reproduction task was counterbalanced dependent on the Presence of Agency manipulation, such that trials were presented in the order of ABAB…AB or BABA…BA. Within each Agency or No Agency block the valence the face stimuli changed to was assigned randomly and was the same valence throughout the block. The actor from which the faces in each trial were sourced was then picked at random. Four of the actors (2, 7, 28 and 36) were repeated twice in each block. The experiment comprised of 240 trials and took approximately 1hr 15 minutes.

Results

Trials with reproduction errors that exceeded 3SD from the individual's mean were removed (0.53% of trials). Mean reproduction errors in each condition for each participant were analysed using a 2 (Presence of Agency) X 2 (Valence) ANOVA (see *Figure* 35). A significant main effect of Presence of Agency was found, $F(1, 31) = 86.69$, $p < .001$, $\eta p^2 = .74$. These effects are due to larger reproduction errors in the Agency condition than the No Agency condition (M = -232ms, SD = 196, and M = -82ms, SD = 208, respectively). This replicates the basic temporal binding effect under conditions of present and absent of agency. The main effect of Valence and the interaction were both non-significant, $F(1, 31) = .014$, $p = .91$, $\eta p^2 < .001$, and $F(1, 31) = .01$, $p =.92$, $\eta p^2 <$ .001, respectively.

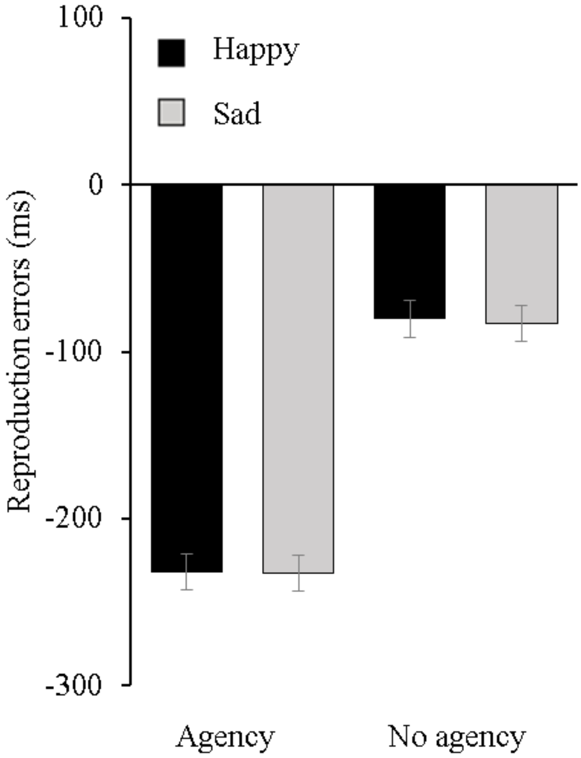

Figure 35. Mean reproduction errors across factors Presence of Agency and Valence for Experiment 7. Bars extending below the x-axis reflect temporal binding.

The levels of social phobia, were considered for the extent to which they may modulate the difference in implicit sense of agency over positively and negatively valenced facial expressions across Agency and No Agency conditions. Happy Reproduction Error Differential, Sad Reproduction Error Differential and Valence Reproduction Error Differential were therefore correlated with SPIN scores. A Pearsons correlation revealed a significant negative correlation between SPIN and Happy Reproduction Error Differential, *r*(30) = -.404, *p* = .022 (see Figure 36) revealing greater temporal binding for Happy faces in Agency conditions compared with No Agency conditions for greater SPIN scores.

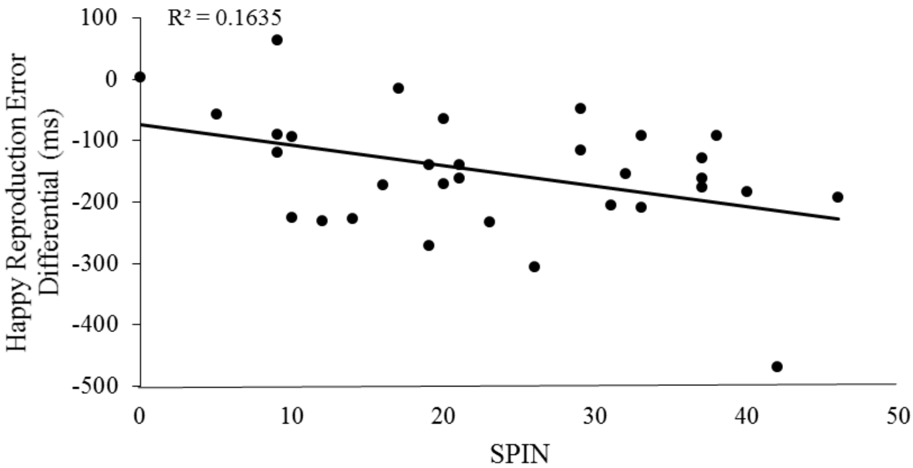

Figure 36. The negative relationship between Happy Reproduction Error Differential and SPIN scores (*r* = -.404). As Happy Reproduction Error Differential increases, SPIN scores decrease. Happy Reproduction Error Differential scores below zero reflect greater temporal binding for Agency conditions compared with No Agency conditions.

The correlation between SPIN and Sad Reproduction Error Differential was not significant, *r*(30) = -.274, *p* = .13 (see Figure 37). These correlation coefficients do not significantly differ from each other (*z* = -0.56, *p* = .58).

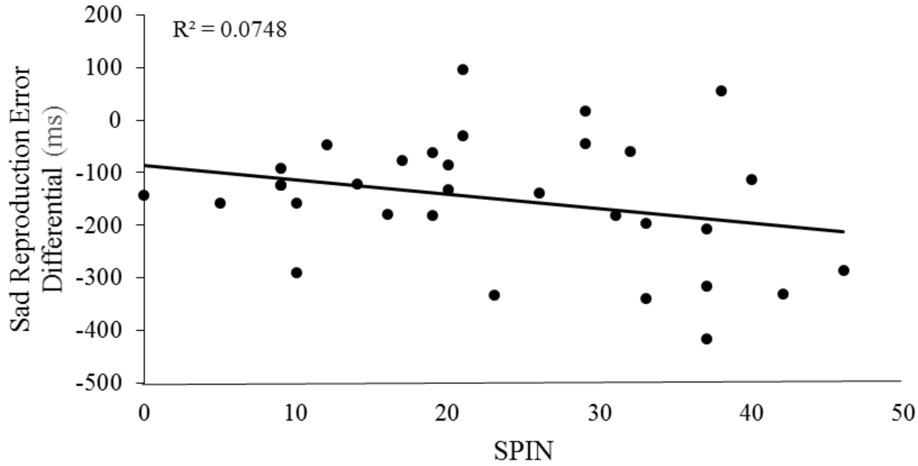

Figure 37. The non-significant relationship between Sad Reproduction Error Differential and SPIN scores.

The correlation between SPIN and Valence Reproduction Error Differential was also not significant, *r*(30) = -.06, *p* = .74 (see Figure 38). These data are therefore considered to provide limited evidence for the effects of social anxiety and the valence of outcomes on the implicit sense of agency.

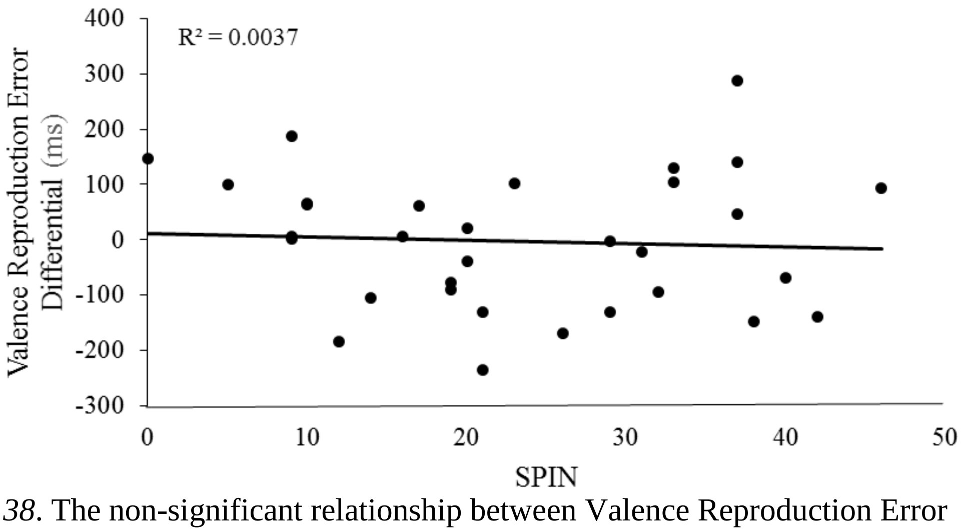

Figure 38. The non-significant relationship between Valence Reproduction Error Differential and SPIN scores.

Discussion

In general the data indicate binding effects because temporal binding was greater under conditions of Agency compared with No agency. This replicates previous findings (Buehner & Humphreys, 2009; Engbert & Wohlschläger, 2007; Engbert et al., 2007;

Haggard et al., 2002; Humphreys & Buehner, 2010). Of interest here was the effect of the valence of the facial expression responses to actions on the implicit measure of agency. Contrary to predictions, the data indicated no significant differences in temporal binding across the different valences of facial expression. Previous data examining the role of socially valenced outcomes to actions for agency have been mixed (Yoshie & Haggard, 2013, Moretto et al., 2011; Christensen et al., 2016). The pattern of data observed here replicates the findings of Christensen et al. (2016) whereby implicit measures of agency did not differ across positive and negative action outcomes.

Also considered was the role of social anxiety for the degree of temporal binding over actions which caused valenced facial expression responses. It was expected that individuals high on social anxiety may either show increased temporal binding for negative stimuli, driven by enhanced self-reference of direct gaze negative faces, or they would show reduced binding for negative stimuli, driven by attentional resource depletion for agency construction. The data indicate no effects of social anxiety on negative faces. Instead, effects for positive faces were found, whereby when high on social anxiety, there was a greater difference in reproduction error differential, such that temporal binding was greater for happy faces under conditions of agency, compared with conditions absent of agency. This indicates that high social anxiety leads to enhanced agency over positive social outcomes. This is contrary to what was expected given that previous findings report increased attentional pull towards negative stimuli in anxious individuals (Mansell et al., 2002; Mogg et al., 2004; Pishyar et al., 2004). The findings here may therefore be reflective of enhanced vigilance of positive outcomes to actions in those with social anxiety. This is a notion that is receiving increased empirical interest, finding that positive stimuli do capture attention in a manner similar to negative stimuli (Pool, Brosch, Delplanque & Snader, 2016). However, in anxiety, this bias is dependent on individual motivations and anxious concerns. Here only facial stimuli with direct gaze was examined. Differences in the implicit measure of agency across valence may therefore be elicited when introducing averted gaze. The condition of averted gaze is therefore introduced in Experiment 8.

Experiment 8: The role of gaze orientation of social responses for implicit agency

Experiment 8 aimed to examine the effects of gaze orientation on social emotional responses to actions on the implicit sense of agency. Like in Experiment 7, implicit sense of agency was measured using an interval reproduction task. Participants made temporal reproductions of intervals between their keypress and the consequence, a socially valent facial expression which was either engaging in direct or averted gaze throughout the trial. The socially valent facial expression was either positive- happy, or negative, disgust. The use of disgust faces to replace sad faces, as used in Experiment 7, was undertaken in order to evoke a greater sense of meaning for the self. Sad faces can be the result of inner mood, whereas disgust faces tend to be a result of an external event. Again, like in Experiment 7, levels of social anxiety were assessed using the SPIN. It was expected that the manipulation of gaze orientation would modulate implicit agency such that averted gaze would result in reduced temporal binding. This is because the facial expressions used were believed to be more self-relevant to the observer, i.e. the participant, when gaze of the stimuli was direct. The role of facial expression valence and gaze orientation was further examined for their relationship with social anxiety in modulating the sense of agency, aiming to replicate findings in Experiment 7 whereby positive stimuli enhances the difference in temporal binding across conditions of agency for those high on social anxiety.

Methods

Participants

Thirty-seven participants aged 18-25 years (*M* = 19.4 *SD* = 1.48, ten were men), completed the experiment for course credit or payment. Participants were recruited from the University of East Anglia and gave informed consent and were also naive as to the research question. The study was approved by the School of Psychology Research Ethics Committee, University of East Anglia.

Apparatus and Stimuli

With the exception that stimuli were presented on a black background, stimuli were presented and the assessment of empathy and social phobia was as in Experiment 7. The actors in the images of the NimStim Face Stimulus set (Tottenham et al., 2009) remained the same as in experiment 7, however, the facial expressions used were neutral open mouthed and happy open mouthed, as in Experiment 7, and unlike Experiment 7, disgust. Open mouthed disgust stimuli were used for actors 7 and 10, and closed mouthed disgust stimuli was used for the remaining actors. The gaze orientation of the facial stimuli were either direct, as in Experiment 7, or averted (Figure 39). Averted eye gaze orientation was manipulated using the GNU Image Manipulation Program to move the pupils to give the impression that the facial stimuli were looking to the left hand side of the screen

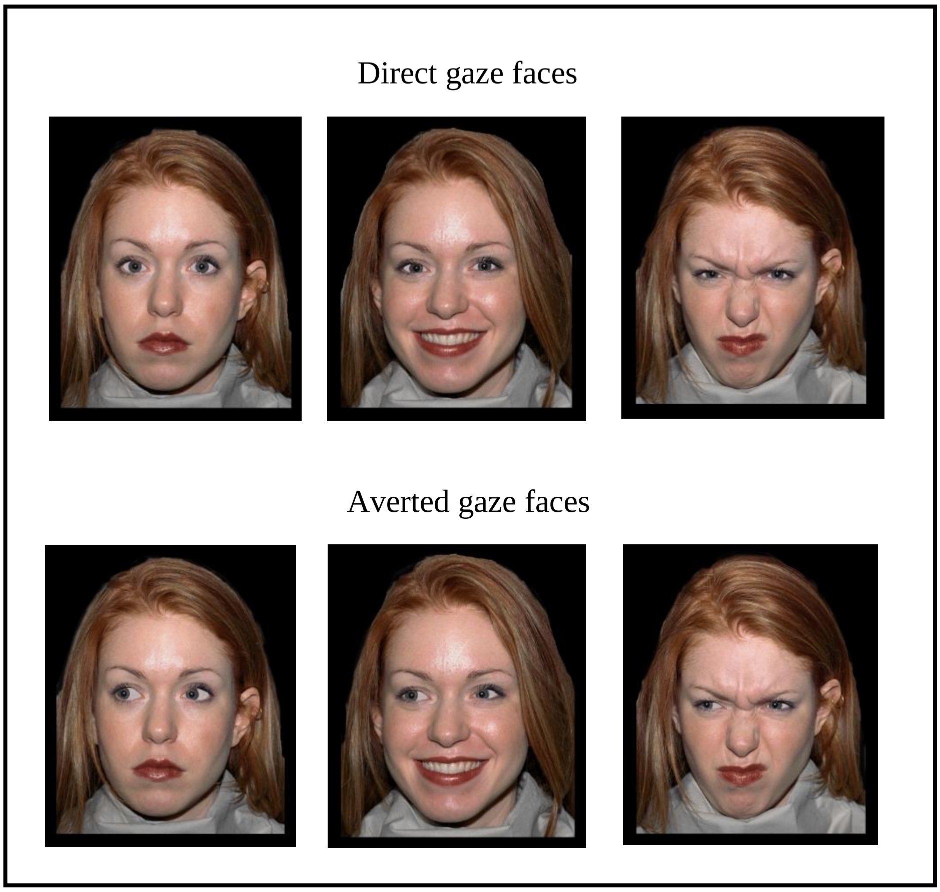

Figure 39. Examples of the facial expression stimuli used in Experiments 8 and 9. Gaze was either orientated direct or averted for entire trials. Model shown is number 1 of the NimStim face stimulus set (Tottenham et al., 2009) showing neutral, happy and disgust facial expressions.

Design

In a 2 x 2 x 2 repeated measures design participants completed eight experimental block types. Block types differed across three factors: Presence of Agency (Agency and No Agency), Valence of facial expression (Happy and Disgust), and Gaze Orientation (Direct and Averted). The dependent measure was the duration of reproduction error. Reproduction error was calculated as the actual interval minus the reproduced interval. Levels of empathy and social phobia were also measured using the EQ (Baron-Cohen & Cartwright, 2004) and the SPIN (Connor et al., 2000), respectively. As in Experiment 7, levels of empathy did not modulate temporal binding and so are not further discussed.

Four temporal binding difference variables were also calculated across the Valence and Gaze Orientation manipulations: Direct Happy Reproduction Error Differential: Agency Direct Happy – No Agency Direct Happy; Direct Disgust

Reproduction Error Differential: Agency Direct Disgust – No Agency Direct Disgust; Averted Happy Reproduction Error Differential: Agency Averted Happy – No Agency Averted Happy; and Averted Disgust Reproduction Error Differential: Agency Averted Disgust – No Agency Averted Disgust. Like in Experiment 7, Valence Reproduction Error Differentials were also calculated but separately for Direct and Averted gaze conditions: Direct- *or* Averted- Valence Reproduction Error Differential [Agency Happy – No Agency Happy] – [Agency Sad – No Agency Sad]).

Procedure

The Presence of Agency and Valence factors were manipulated as in Experiment 7, however, note the differences in Valence across Experiments 7 and 8 whereby in Experiment 7 happy and sad facial expressions were used, whereas in Experiment 8 happy and disgust facial expression were used. Gaze orientation was manipulated such that in Direct gaze orientation conditions the eyes looked forwards for the entire trial and is therefore the same as Experiment 7. In Averted gaze orientation conditions the orientation of the eyes was such that they were looking to the left hand side for the entire trial (see Figure 40 for the Interval Reproduction task procedure, and Valence and Gaze Orientation manipulations for Experiment 8).

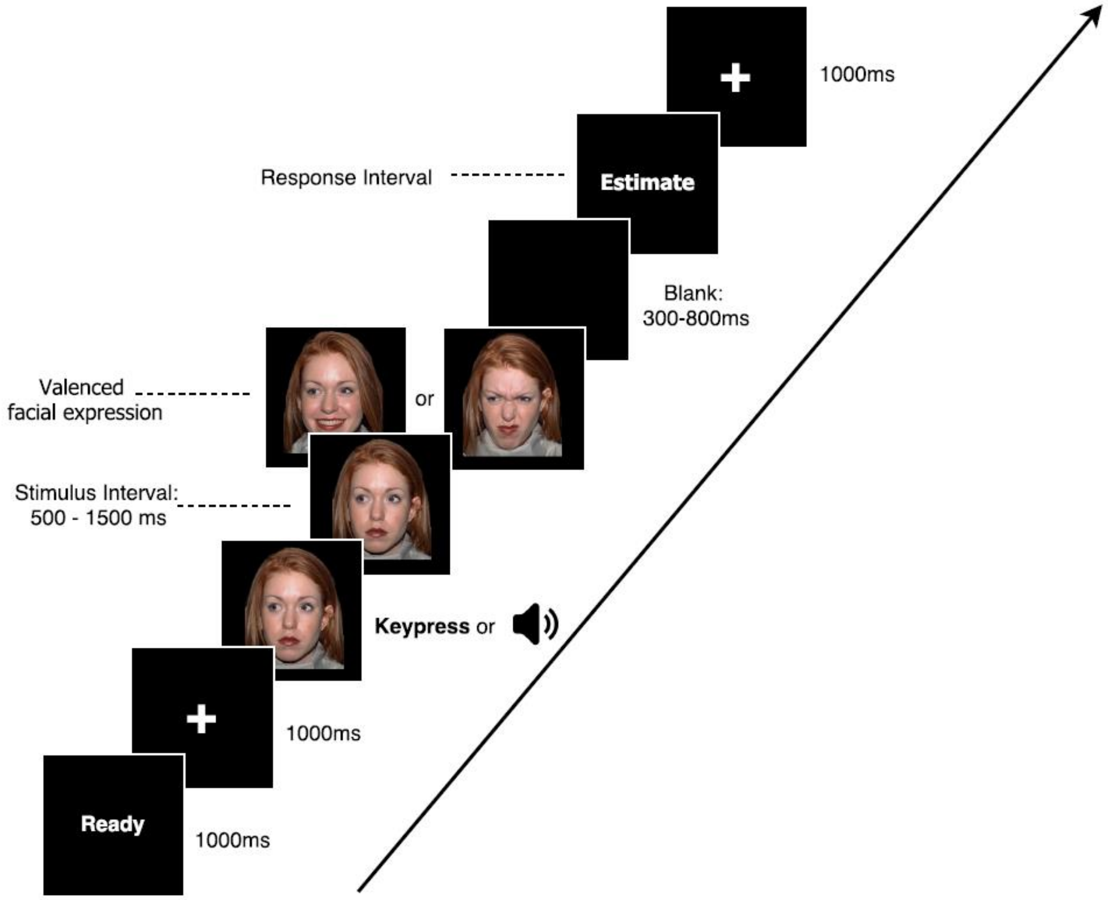

Figure 40. Procedure for the Interval Reproduction task in Experiment 8. In each condition participants were presented with a series of facial stimuli of which the gaze was orientated either Direct or Averted. Showed here is averted gaze only. The first stimuli presented was a neutral face after which the first event occurred, either a key press (Agency) or a tone (No Agency). After a randomised stimulus interval (set at 500, 750, 1000, 1250 or 1500ms) the outcome, a valenced facial expression, either Happy or Disgust, was presented. Participants were instructed to respond by recreating the duration between the first event and the change in facial expression by the depression of the spacebar.

Before starting the experiment participants completed a short practice block involving the Presence of Agency, Valence and Gaze Orientation manipulations. Each experimental condition consisted of 32 trials which were presented in two blocks, 16 trials per block. The experiment therefore consisted of 16 blocks. The administration of the scales and Interval Reproduction tasks was counterbalanced as in Experiment 7. The order of blocks in the Interval Reproduction tasks was counterbalanced dependent on the

Presence of Agency manipulation, such that trials were presented in the order of ABAB…AB or BABA…BA. Within each Agency or No Agency block the valence the face stimuli changed to was assigned randomly, as was the gaze orientation, and kept the same throughout the block. The actor from which the faces for each trial were sourced was then picked at random. The experiment consisted of 256 trials and lasted approximately 80 minutes.

Results

Trials with reproduction errors that exceeded +/- 3SD from the individual's mean were removed (0.63% of trials). Mean reproduction errors in each condition for each participant were analysed using a 2 (Presence of Agency) X 2 (Valence) X 2 (Gaze Orientation) ANOVA (see Figure 41). As in Experiment 7 we replicated the basic temporal binding effect with a significant main effect of Presence of Agency, $F(1, 36) = 19.7$, $p < .001$, $\eta p^2 = .354$. These effects are due to larger reproduction errors in the Agency condition than the No Agency condition (M = -76ms, SD = 270, and M = 2ms, SD = 219, respectively). The main effects of Valence and Gaze Orientation were not significant, $F(1, 36) = .786$, $p = .381$, $\eta p^2 = .021$, and $F(1, 36) = .054$, $p =.817$, $\eta p^2 = .002$, respectively. The Presence of Agency X Valence; Presence of Agency X Gaze Orientation and Valence X Gaze Orientation interactions were also not significant, $F(1, 36) = 1.149$, $p = .291$, $\eta p^2 = .031$, $F(1, 36) = .019$, $p = .89$, $\eta p^2 = .001$, and $F(1, 36) = .077$, $p = .783$, $\eta p^2 = .002$, respectively. The 3-way interaction was significant, $F(1, 36) = 4.318$, $p = .045$, $\eta p^2 = .107$. To establish the source of the 3-way interaction, 2-way ANOVAs were conducted across each level of Valence and Gaze Orientation. These analyses confirmed that the significant three-way interaction was driven by a significant Presence of Agency X Valence interaction for the direct gaze orientation, $F(1, 36) = 4.249$, $p = .047$, $\eta p^2 = .106$. This was due to greater reproduction errors for Disgust faces under Agency conditions compared with No Agency conditions, $t\,(36) = 4.79$, $p < .001$, $d_z = 0.79$, whereas, comparable reproduction errors were observed for Happy faces across Agency and No Agency conditions, $t\,(36) = 1.41$, $p = .167$, $d_z = 0.23$. This latter finding was not expected. Typically, Agency conditions produce enhanced reproduction errors compared to No Agency conditions. The Presence of Agency X Valence interaction was not significant for Averted gaze, $F(1, 36) = .655$, $p = .424$, $\eta p^2 = .018$. It therefore considered that the Presence of Agency manipulation was not successful for happy direct gaze conditions.

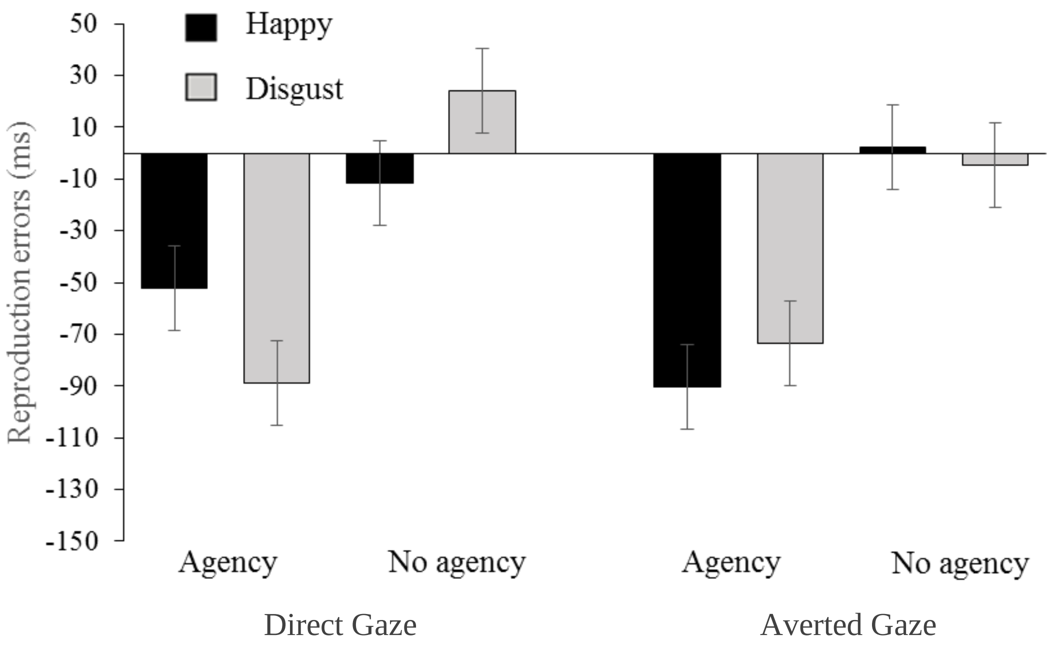

Figure 41. Mean reproduction errors across factors Presence of Agency, Valence and Gaze Orientation for Experiment 8. Bars extending below the x-axis reflect temporal binding.

As in Experiment 7, the levels of social phobia, assessed using the SPIN, were considered for their modulation over the implicit sense of agency over positively and negatively valenced facial expressions, and also across gaze orientation. The relationships between SPIN and Reproduction Error Differentials across the Gaze and Valence manipulations were therefore examined with four correlations. A Pearsons correlation revealed a significant positive correlation between SPIN and Direct Happy Reproduction Error Differential, $r(35) = .356$, $p = .03$ (see Figure 42). The correlations between SPIN and Direct Disgust, Averted Happy and Averted Disgust Reproduction Error Differentials were not significant, $r(35) = .047$, $p = .784$, $r(35) = .067$, $p = .693$, and $r(35) = -.079$, $p = .643$, respectively (see Figures 43, 44 & 45, respectively).

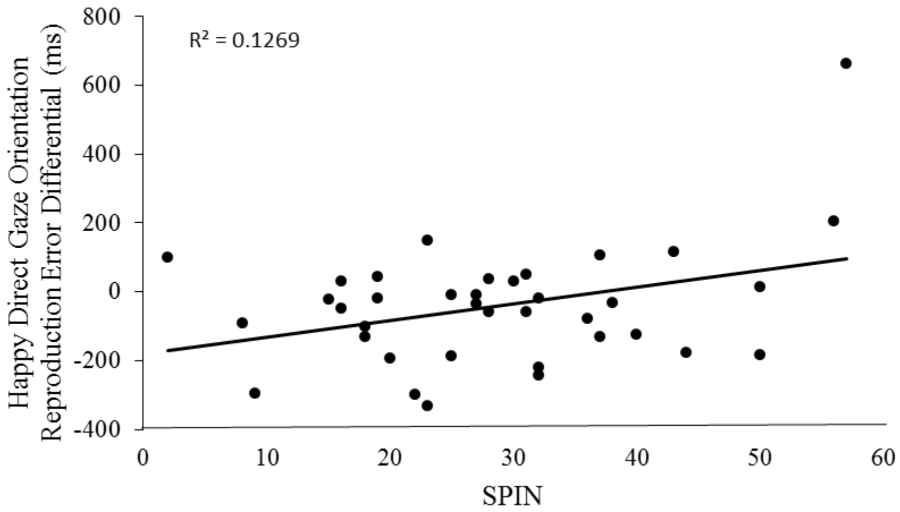

Figure 42. The positive relationship between Happy Direct Reproduction Error Differential and SPIN scores (*r* = .356). As Happy Direct Reproduction Error Differential increases, SPIN scores also increase. Happy Direct Reproduction Error Differential scores below zero reflect greater temporal binding for Agency conditions compared with No Agency conditions.

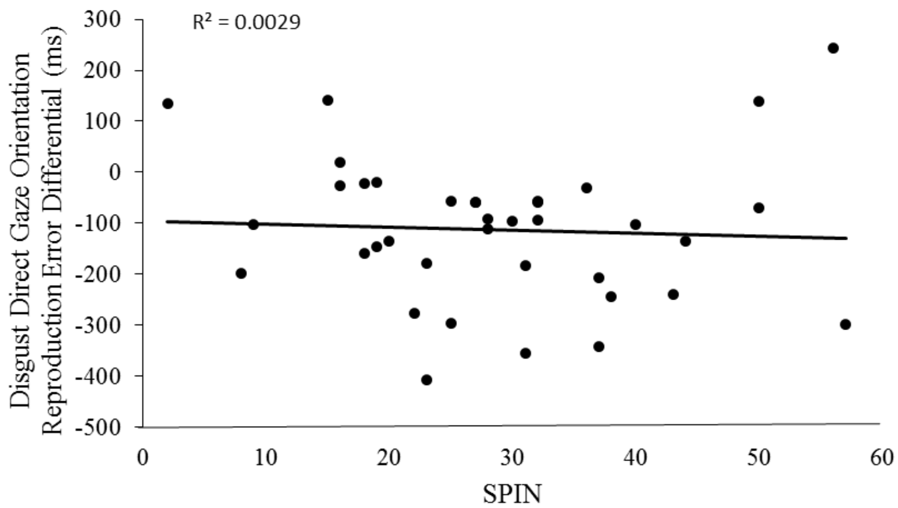

Figure 43. The non-significant relationship between Disgust Direct Reproduction Error Differential and SPIN scores.

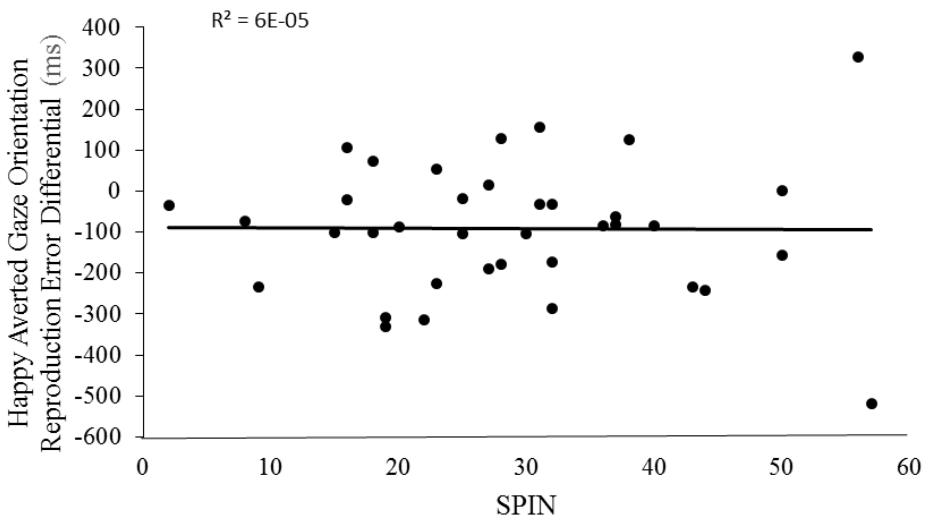

Figure 44. The non-significant relationship between Happy Averted Reproduction Error Differential and SPIN score.

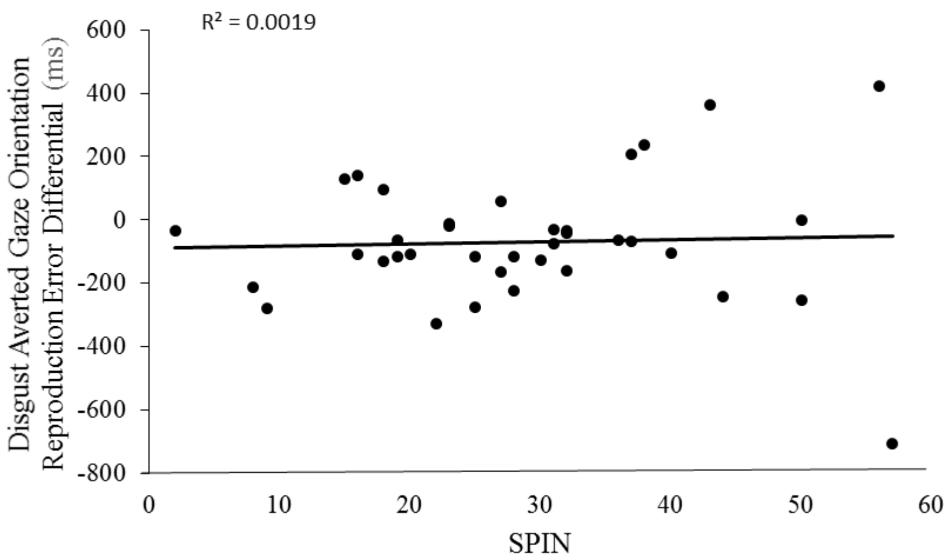

Figure 45. The non-significant relationship between Disgust Averted Reproduction Error Differential and SPIN score.

As in Experiment 7 a relationship between SPIN and Direct Happy faces was observed (note in experiment one there was no manipulation of Gaze Orientation thus faces had direct orientation). However, the correlation coefficients indicate that the correlation is negative in Experiment 7 (r = -.404) and positive in Experiment 8 (r = .356). These correlation coefficients are significantly different from one another (z = -3.17, p = .002).

Like in Experiment 7 Valence Reproduction Error Differentials were calculated, separately for Direct and Averted conditions (see Figures 46 & 47). A Pearson correlation revealed a significant correlation between Direct Valence Reproduction Error Differential and SPIN scores, *r*(35) = .328, *p* = .047, whereby as SPIN scores increase the binding effect (i.e. greater temporal binding under Agency conditions compared to No Agency conditions) for Direct Happy faces reduces, compared to Direct Disgust faces. This effect was not consistent for Averted Valence Reproduction Error Differential, *r*(35) = -.057, *p* = .74.

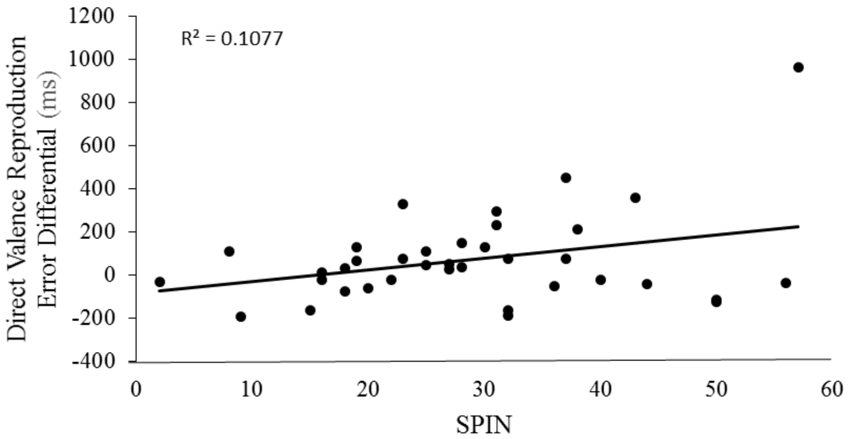

Figure 46. The positive relationship between Direct Valence Reproduction Error Differential and SPIN scores (*r* = .328). As Direct Valence Reproduction Error Differential increases, SPIN scores also increase. Direct Valence Reproduction Error Differential scores below zero reflect a greater binding effect under conditions of Direct Happy faces, compared to Disgust faces.

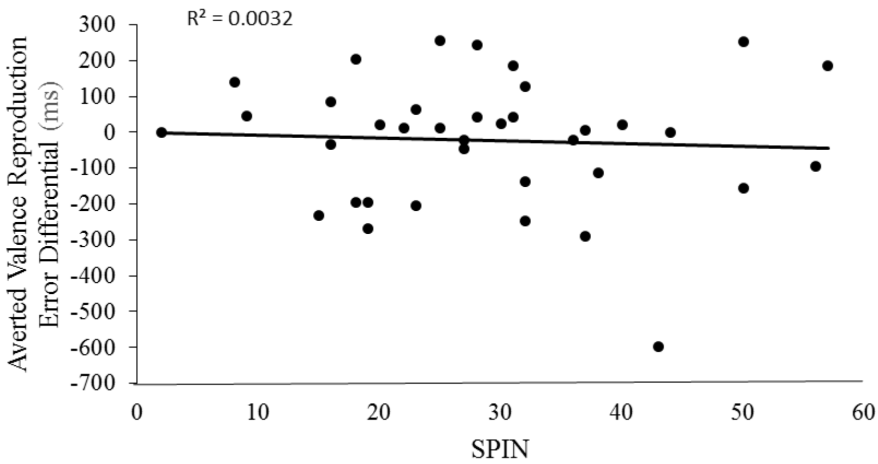

Figure 47. The non-significant relationship between Averted Valence Reproduction Error Differential and SPIN scores.

Discussion

The pattern of data in Experiment 8, as expected, indicates binding effects whereby temporal binding under conditions of agency was greater than under conditions absent of agency. However, of note is that the overall level of binding in Agency conditions is much less that the temporal binding for Agency conditions in Experiment 7. The current experiment also investigated the role of the valence of facial expression responses to actions, and the gaze orientation of these faces, on the sense of agency. Like in Experiment 7, Experiment 8 did not find an effect of stimuli valence on temporal binding even when gaze orientation was introduced as a factor. This replicates the null findings of valence on implicit measures of agency in Christensen et al. (2016).

The role of social anxiety for the degree of temporal binding over actions was also considered. Experiment 7, which examined direct gaze orientation, indicated that for happy faces an increase in social anxiety resulted in greater reproduction error differential, in that there was greater temporal binding under agency conditions compared with no agency conditions. In the current experiment, again an effect on direct gaze and happy stimuli was observed. However, this effect was in the opposite direction, whereby an increase in levels of social anxiety resulted in decreased agency effects, i.e. the difference in temporal binding between agency and no agency conditions reduced, or became more comparable. Although this effect is in the opposite direction to that observed in Experiment 7, the pattern of data here are perhaps arguably more appropriate. On their own, these data may suggest an insensitivity of agency effects on the happy valenced direct gaze stimuli in socially anxious individuals. However, the patterns of data observed in Experiments 7 and 8 indicate that the effects of valenced social emotional stimuli is unclear. The use of dynamic gaze stimuli, whereby the faces in the stimuli change their orientation during the trial, is believed to offer a more natural context with which to examine the effects of gaze orientation. Dynamic gaze stimuli are used Experiment 9.

Experiment 9: The role of dynamic gaze orientation of social responses for implicit agency

Experiment 9 aimed to investigate the effects of dynamic gaze orientation of social emotional responses to actions on the implicit sense of agency. Like in Experiments 7 and 8, implicit sense of agency was measured using an interval reproduction task. In this experiment the valent facial expression engaged in dynamic direct or averted gaze. During a trial, the facial stimuli changed orientation 500ms before the valent facial expression. The socially valent facial expression was either positive-happy, or negative – disgust and so is a near replication of Experiment 8. Again, levels of social anxiety were assessed using the SPIN. It is expected that the manipulation of dynamic gaze orientation would serve as a more naturalistic investigation of gaze orientation in Experiment 9 (Sato, Yoshikawa, Kochiyama & Matsumura, 2004), and will help to clarify the relationship between sense of agency, social emotional responses to actions and social anxiety.

Methods

Participants

Thirty-nine participants aged 18-36 years (*M* = 20, *SD* = 4.36; five were men), completed the experiment for course credit or payment. Participants were recruited from the University of East Anglia and gave informed consent and were also naive as to the research question. The study was approved by the School of Psychology Research Ethics Committee, University of East Anglia.

Apparatus and Stimuli

Stimuli were presented, social phobia was assessed and participants were tested as in Experiment 8. The images of the NimStim Face Stimulus set (Tottenham et al., 2009) remained the same as in Experiment 2.

Design

In a 2 x 2 x 2 repeated measures design participants completed eight experimental block types. Block types differed across two factors: Presence of Agency (Agency and No Agency), Valence of facial expression (Happy and Disgust), and Dynamic Gaze

Orientation (Direct and Averted). Facial stimuli were the same as those used in Experiment 8, see Figure 39 for examples of the facial stimuli used. The dependent measure was the duration reproduction error. Reproduction error was calculated as the actual interval minus the reproduced interval. Levels of social phobia were measured using the SPIN (Connor et al., 2000). Temporal binding difference variables were calculated across the Valence and Dynamic Gaze Orientation manipulations as in Experiment 8 to give Direct Happy, Direct Disgust, Averted Happy and Averted Disgust Reproduction Error Differentials. Like in Experiments 7 and 8 Valence Reproduction Error Differentials were also calculated, separately for Direct and Averted conditions.

Procedure

The presence of agency was manipulated as in Experiments 7 and 8. Valence was manipulated as in Experiment 8. Dynamic Gaze Orientation was manipulated such that 500ms before the facial expression changed the orientation of the gaze shifted. In Direct conditions from the beginning of the trial the gaze was averted, orientated left, and then shifted to an orientation looking straight forwards. In Averted conditions from the beginning of the trial the gaze orientation was straight forwards and then shifted to being averted, orientated to the left. Before starting the experiment participants completed a short practice block involving the Presence of Agency, Valence and Gaze Orientation manipulations (see Figure 48 for the Interval Reproduction task procedure and Valence and Dynamic Gaze Orientation manipulations for Experiment 9).

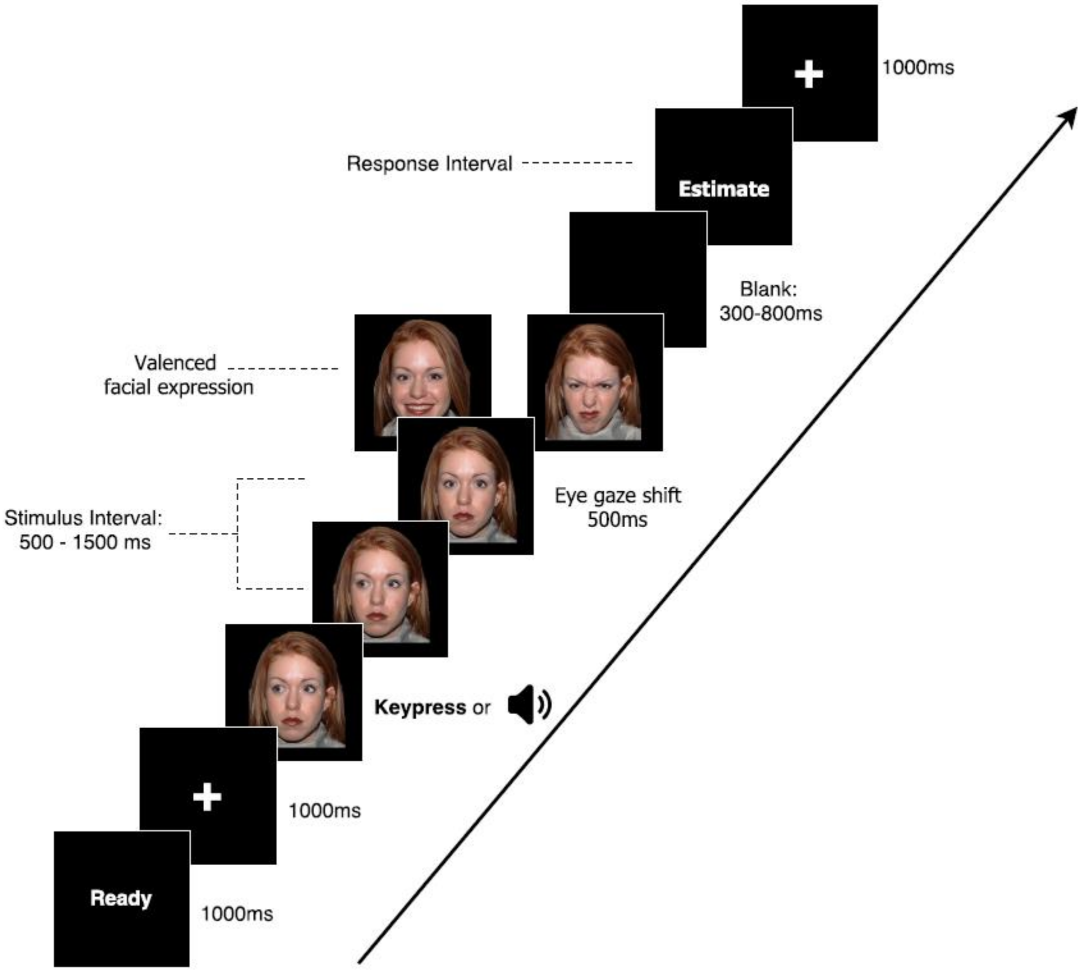

Figure 48. Procedure for the Interval Reproduction task in Experiment 9. The schematic illustrate, in particular, a trial in the Direct eye gaze orientation condition. In each condition participants were presented with a series of facial stimuli. The first stimuli presented was a neutral face which was oriented either forwards (Averted) or to the left (Direct) after which the first event occurred, either a key press (Agency) or a tone (No Agency). A randomised stimulus interval (set at 500, 750, 1000, 1250 or 1500ms) consisted of the neutral facial expression (jittered at 0-1000ms) and the neutral facial expression whereby the eye gaze shifted (500ms). The stimulus interval was followed by a valenced facial expression, either Happy or Disgust. Participants were instructed to respond by recreating the duration between the first event and the change in facial expression with the depression of the spacebar. In Direct conditions the eye gaze begins with an averted orientation and shifts eye gaze to be Direct. In Averted conditions the eye gaze begins with a direct orientation and shifts eye gaze to be Averted.

Each experimental condition consisted of 32 trials which were presented in two blocks, 16 trials per block. The experiment therefore consisted of 16 blocks. The administration of the scales and Interval Reproduction tasks was counterbalanced as in Experiments 7 and 8. The order of blocks and the order of stimulus presentation in the Interval Reproduction tasks was counterbalanced as in Experiment 8. The experiment consisted of 256 trials and lasted approximately 80 minutes.

Results

Trials with reproduction errors that exceeded +/- 3SD from the individual's mean were removed (0.63% of trials). Mean reproduction errors in each condition for each participant were analysed using a 2 (Presence of Agency) X 2 (Valence) X 2 (Dynamic Gaze Orientation) ANOVA (see Figure 49). As in Experiments 7 and 8 the typical temporal binding effect was replicated with a significant main effect of Presence of Agency, $F(1, 38) = 131.97$, $p < .001$, $\eta p^2 = .776$. These effects are due to larger reproduction errors in the Agency condition than the No Agency condition (M = -178ms, SD = 279, and M = -49ms, SD = 296, respectively). The main effects of Valence and Dynamic Gaze Orientation were not significant, $F(1, 38) = .7$, $p = .41$, $\eta p^2 = .018$ and $F(1, 38) = .089$, $p = .767$, $\eta p^2 = .002$, respectively. The Presence of Agency X Valence, Presence of Agency X Dynamic Gaze Orientation, and Valence X Gaze Orientation interactions were also not significant, $F(1, 36) = 1.44$, $p = .238$, $\eta p^2 = .036$, $F(1, 36) = 2.33$, $p = .135$, $\eta p^2 = .058$, and $F(1, 36) = .002$, $p = .97$, $\eta p^2 < .001$, respectively. The 3-Way interaction was also not significant, $F(1, 36) = .4$, $p = .531$, $\eta p^2 = .01$.

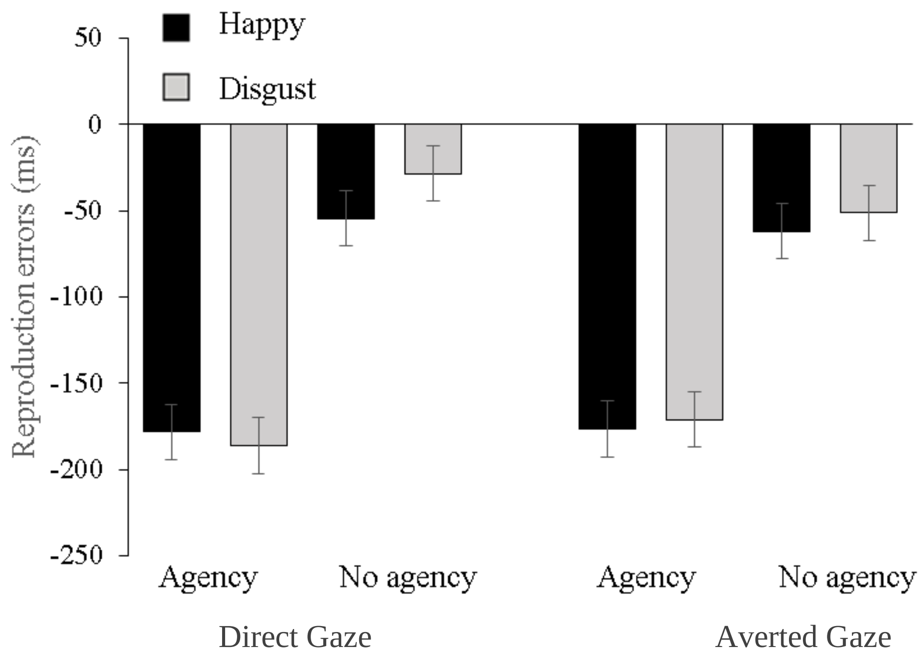

Figure 49. Mean reproduction errors across factors Presence of Agency, Valence and Dynamic Gaze Orientation for Experiment 9. Bars extending below the x-axis reflect temporal binding.

Levels of social anxiety, assessed using the SPIN, were considered for their modulation of temporal binding across Valence and Dynamic Gaze Orientation manipulations. The four Reproduction Error Differentials across Valence and Gaze orientation variables were therefore correlated with SPIN scores. Pearson correlations revealed non-significant relationships between SPIN and the Direct Happy, Direct Disgust, Averted Happy and Averted Disgust Reproduction Error Differentials, $r(37) = -.066$, $p = .691$, $r(37) = -.048$, $p = .773$, $r(37) = .149$, $p = .365$ and $r(37) = -.016$, $p = .922$, respectively (see Figures 50, 51, 52 & 53).

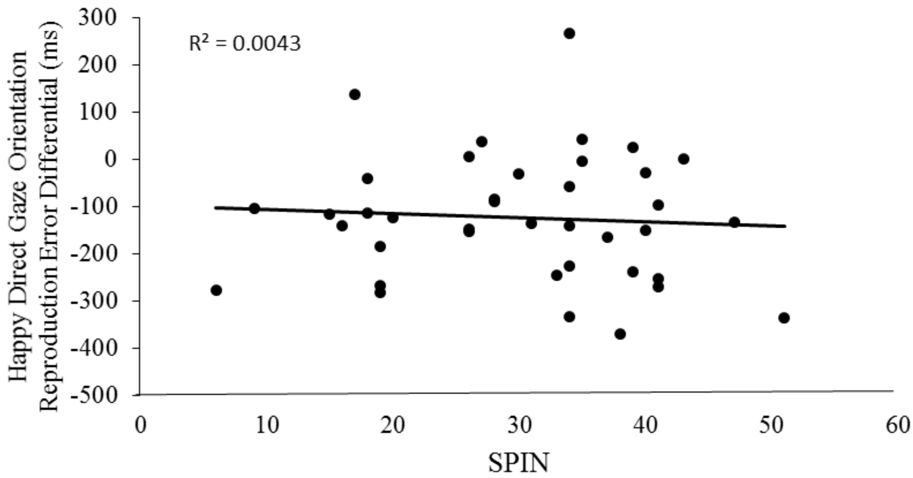

Figure 50. The non-significant relationship between Happy Direct Reproduction Error Differential and SPIN scores.

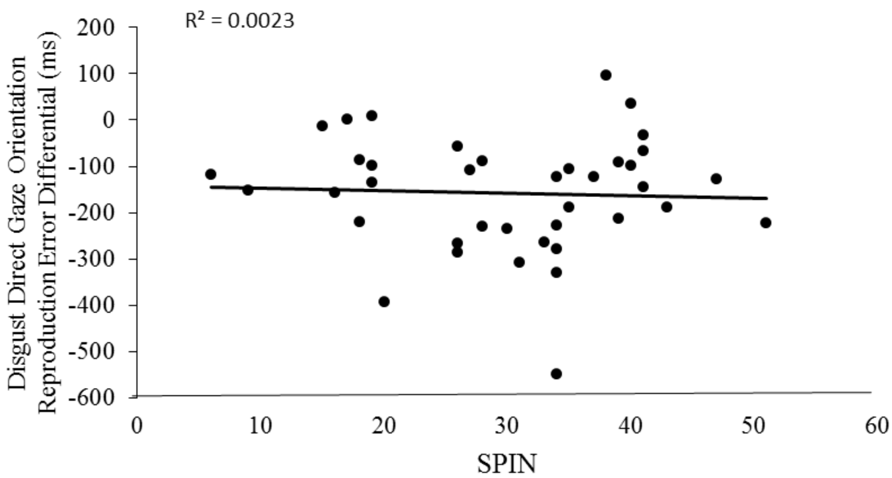

Figure 51.. The non-significant relationship between Disgust Direct Reproduction Error Differential and SPIN scores.

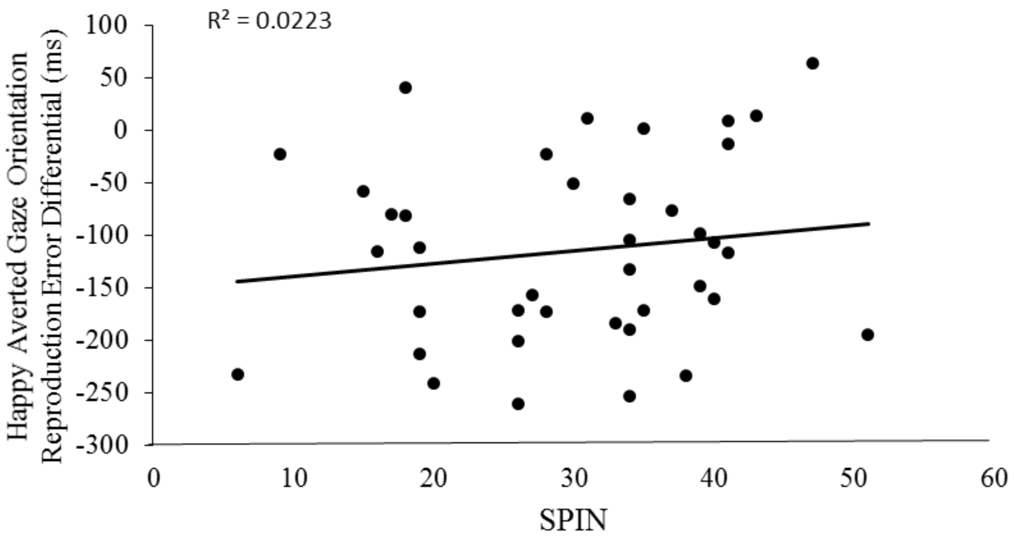

Figure 52. The non-significant relationship between Happy Averted Reproduction Error Differential and SPIN scores.

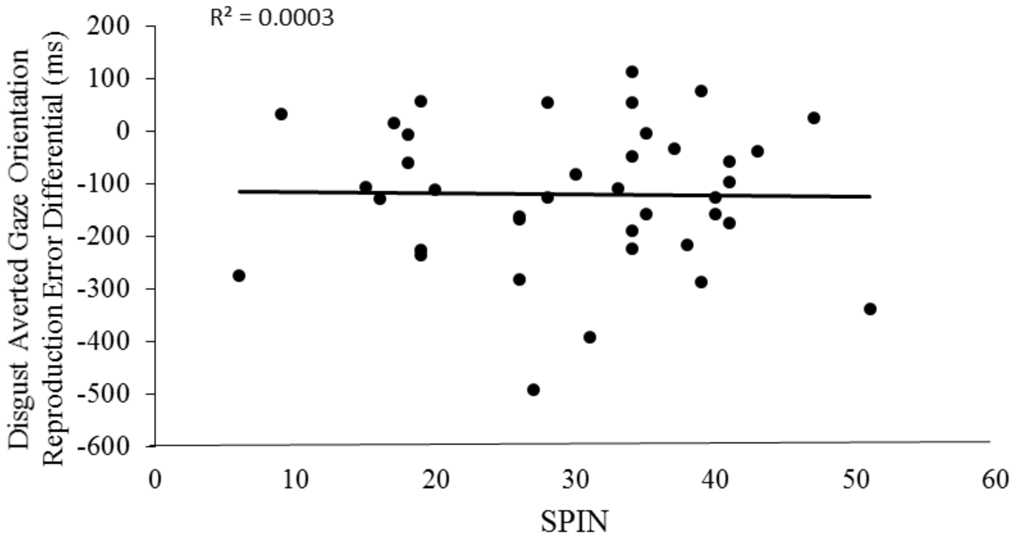

Figure 53. The non-significant relationship between Disgust Averted Reproduction Error Differential and SPIN scores.

Like in Experiments 7 and 8 Valence Reproduction Error Differentials were calculated separately for Direct and Averted conditions. Two Pearson correlations revealed non-significant correlations between Direct Valence Reproduction Error Differential and SPIN scores, $r(37) = -.014$, $p = .933$, and Averted Valence Reproduction Error Differential and SPIN scores, $r(35) = .109$, $p = .51$ (see Figures 54 & 55).

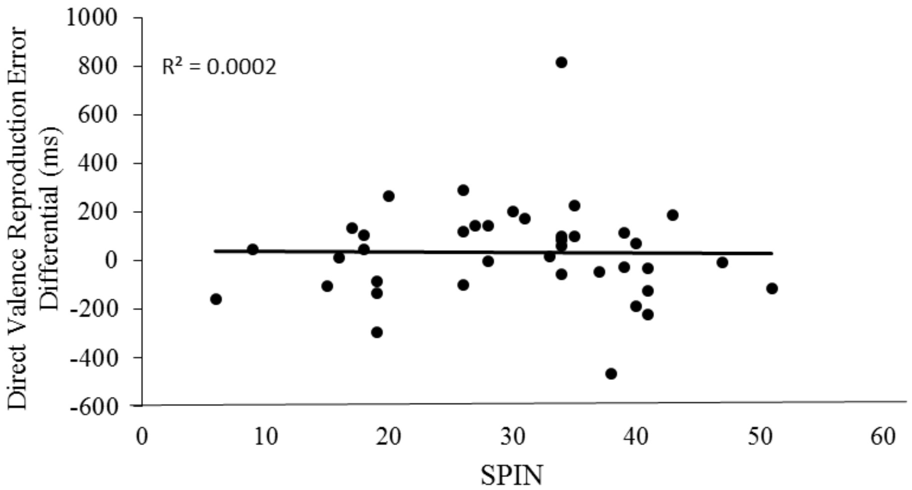

Figure 54. The non-significant relationship between Direct Valence Reproduction Error Differential and SPIN scores.

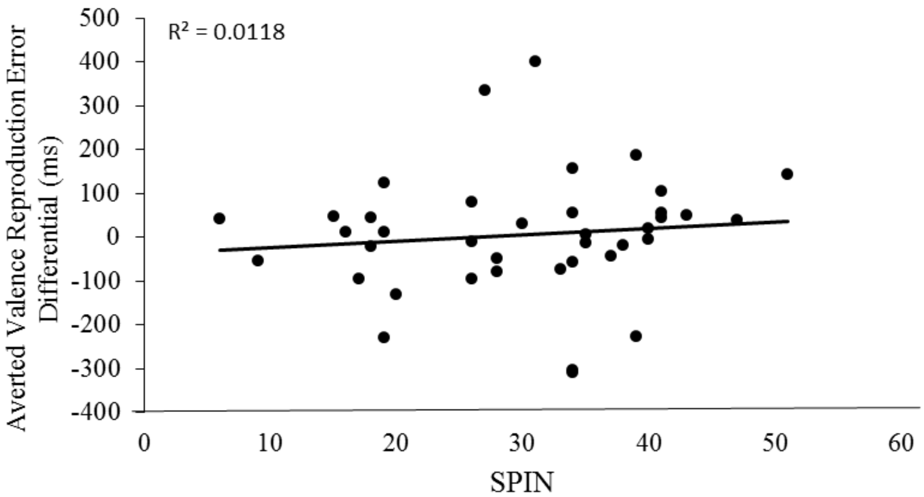

Figure 55. The non-significant relationship between Averted Valence Reproduction Error Differential and SPIN scores.

Discussion

As in Experiments 7 and 8 the pattern of data in Experiment 9 indicate binding effects whereby temporal binding under conditions of agency was greater than under conditions absent of agency. The Experiment 9 also investigated the role of the valence of facial expression responses to actions, and dynamic gaze orientation of these faces, on the sense of agency. In Experiments 7 and 8 agency was not modulated by facial expression valence, replicating Christensen et al. (2016). Overall, Experiment 9 also did not find effects of stimuli valence or dynamic gaze orientation on temporal binding. Again, the role of social anxiety for the degree of temporal binding over actions was also considered. Previous experiments conducted in the current chapter indicate that the role of social anxiety is mixed and unclear. Experiment 7, found a negative correlation between reproduction error differential and social anxiety scores, whereas Experiment 8 found a positive relationship between these variables. The current experiment did not find a modulating role of social anxiety.

General discussion

The current experimental chapter investigated the effects of social emotional action outcomes across differing gaze orientations on the implicit temporal binding measure of the sense of agency. How these effects may be modulated by individual differences in social anxiety was also examined. An interval reproduction temporal binding method was used as an implicit measure of agency (Engbert & Wohlschläger, 2007; Engbert et al., 2007; Haggard et al., 2002; Moore & Obhi, 2012). The NimStim (Tottenham et al., 2009) social emotional stimuli set were presented to participants such that a neutral face changed to an emotional facial expression after an action (keypress) or a prior tone. The gaze orientation of the face set stimuli was also manipulated such that gaze was either oriented direct or averted. There were several similarites and differences across the three experiement which are clarified here: Experiment 7 examined direct gaze faces with either happy or sad expressions. Experiment 8 examined direct or averted gaze faces with happy or disgust expressions. Experiment 9 examined dynamic gaze orientation (to direct gaze from averted, and vice versa) with faces with either happy or disgust expressions.

Across the three experiments typical agency effects were observed, whereby temporal binding was greater under conditions of agency compared to no agency. This effect was consistent across all three experiments with large statistical effect sizes (Experiment 7 – $\eta_p^2 = .74$; Experiment 8 - $\eta_p^2 = .35$; Experiment 9 - $\eta_p^2 = .78$) effects replicate much prior work which use various methods of measuring the sense of agency (Buehner & Humphreys, 2009; Engbert et al., 2007; Engbert & Wohlschläger, 2007; Haggard et al., 2002; Humphreys & Buehner, 2010; Moore & Obhi, 2012). Of critical interest however, was whether the valence (Experiments 7-9) and gaze orientation

(Experiments 8 & 9) of the social emotional face modulated the degree temporal binding and how individual differences in social anxiety may modulate these effects. Overall, across the three experiments no effect of social emotional valence of the stimuli was found. The degree of temporal binding for positive and negative stimuli was comparable within each condition of agency and no agency. Moreover, there was no effect of gaze orientation on the degree of temporal binding with direct and averted gaze producing similar temporal binding across the Presence of Agency and Valence manipulations. It is important to note that a significant three-way interaction was observed in Experiment 8. In this instance the source of the interaction was due to a non-significant agency effect for direct gaze happy faces, whereby temporal binding was not significantly greater in agency conditions compared with no agency conditions. It is considered that the Presence of Agency manipulation was not successful in this instance because this effect was not consistent in Experiments 7 and 9. This effect is therefore believed to be the result of a type I error in avoidance of over interpreting the data.

Individual differences in social anxiety were also investigated for their modulatory role on the degree of temporal binding for socially valent faces. To do so Reproduction Error Differentials were calculated for each valence type of the social emotion stimuli, and where appropriate, the gaze orientation. This gave a numerical indication as to the degree of temporal binding difference between the Agency and No Agency conditions for each type of the stimuli faces and gaze orientation. In Experiment 7 an interesting relationship between Reproduction Error Differential for direct gaze happy faces and social anxiety score was observed. The nature of this relationship was that as social phobia levels increased greater temporal binding was produced in Agency conditions compared to No Agency conditions. In Experiment 8, the data also revealed a significant relationship between Reproduction Error Differential scores for direct gaze happy faces and social anxiety. However, the nature of this relationship was the opposite of what was found in Experiment 7. In Experiment 8, the data revealed that as social anxiety increased temporal binding produced in Agency conditions was more comparable to that in No Agency conditions. No other significant relationships between Reproduction Error Differential scores and social anxiety were found across the other valence and gaze orientation manipulations in Experiments 7 and 8. Furthermore, in Experiment 9 in which the gaze orientation dynamically oriented from direct to averted and vice versa, and so under conditions which are arguably more naturalistic (Sato et al., 2004), no significant relationships between Reproduction Error Differential scores and social anxiety were found for any of the valence and gaze orientation manipulations. This indicates that since the effects of social phobia on the degree of temporal binding for happy direct gaze oriented faces was not consistent, the effects observed here are likely to not reflect true effects.

Previous research across several distinct areas of literature contributed towards the hypotheses outlined in the current experimental chapter. For instance, individuals have a bias towards positive stimuli and attribute positive events with the self, and dissociate the self from negative events (Wilke et al., 2012). This phenomenon is known as the self-serving bias (Greenberg et al., 1982, Mezulis et al., 2004) and is supported by *some* investigations into the sense of agency which demonstrates that monetary losses and negative social emotional sounds reduce the sense of agency over the actions which caused them (Takahata et al., 2012; Yoshie & Haggard; 2013). The research into the effects of action-outcome valence on the implicit measures of the sense of agency has however, been inconsistent. Whereas Takahata et al. (2012) and Yoshie and Haggard (2013) report reduced agency for negative events, Moretto et al. (2011) found enhanced agency for more severe socially immoral and negative economic action-outcomes. However, in this study only the severity of negative outcomes was manipulated, so comparisons to positive outcomes could not be made. Nevertheless, a close replication of Yoshie and Haggard's (2013) investigation into social emotional sounds reported that the degree of implicit agency over positive and negative action-outcomes was comparable, both when the occurrence of an outcome was predictable and unpredictable (Christensen et al., 2016). The findings in the current chapter that there was no effect of social emotional valence on the implicit measure of agency therefore replicated the findings of Christensen et al.

The reason as to why there is such variance in the effects of valenced social emotional action-outcomes in the current literature is not clear. One explanation for the divergence in findings may be due to individual differences in affective style. The affective coding of agency model (Gentsch & Synofzik, 2014) suggests that the emotional valence of a stimulus can influence the ascription of agency, but also highlights that differences in emotional regulation and affect can mediate this effect. The current experiments therefore examined the role of individual differences in social anxiety since this condition is characterised by enhanced vigilance of social evaluation and deficits in emotional regulation. The examination of social phobia with regards to its modulatory role on agency over social emotional action-outcomes here however, failed to support this notion.

Possible explanations for the observed null effects

The current investigation did not find any effects of social anxiety and the valence of social emotional action-outcomes on the sense of agency. Rather the null effect of social emotional action outcomes, gaze orientation and social anxiety offer some informative boundary contexts to which the implicit measure of agency is not sensitive. Some possible reasons are presented here as to why these factors did not modulate the sense of agency. This can be supported by the findings of Moretto et al. (2011), who found that more severe negative consequences resulted in enhanced temporal binding. It is likely that the increased severity also increased levels of arousal. Given the role of arousal in the internal pacemaker model of subjective time, manipulating the degree of arousal across positive and negative stimuli may elucidate the role of valence and arousal for the sense of agency over outcome-actions.

Limitations and future research

The use of the interval reproduction method as administered in these studies may have caused greater variance in the temporal binding data due to difficulty in carrying out the task. Such variance may have further masked any behavioural effects. The interval reproduction task undertaken by participants in Experiments 7-9 required participants to judge the interval between two events, a keypress and a change in the visually presented facial stimuli, or a beep and a change in the visually presented stimuli. The change in the visual stimuli may have been difficult to time lock in the sense that there is a weaker mental marker of the event than a tone which in typical interval reproduction paradigms is presented at the end of the stimulus interval. Future research may aim to avoid this issue, for which two suggestions in how to this can be conducted are proposed. Firstly, it may be beneficial to use an alternative temporal binding measure to the interval reproduction method, such as the Libet clock method. The Libet clock method may not succumb to this ‘mental marker’ difficulty since participants can spatially pinpoint trial events on the visually presented Libet clock. Alternatively, increasing the strength of the ‘mental marker’ of the events may overcome this issue. For instance, the change in facial expression could be paired with a tone, which is typically used in interval reproduction paradigms to signal the end of the stimulus interval.

It is also possible that the relationship between the action and outcome is not naturalistic since a key press rarely in life causes another to change their facial expression. In order to overcome this issue three methodological changes are proposed. Firstly, the action could reflect one that genuinely would cause the elicitation of a valenced facial expression, such as enacting rude or positive hand gesture, or breaking an object. Alternatively, the keypress action used in the current studies could cause an effect which would elicit an emotional response, such as the giving or taking away of a monetary reward. The third change is the use of a confederate or second participant who responds to the actor's positive or negative actions. These methodological differences would reinforce the importance of the action to the outcome which may be reflected in the temporal binding measure of agency over the action.

The experiments in the current chapter aimed to investigate individual differences in social anxiety for its role in modulating the implicit sense of agency over social emotional events due to the highlighted implications of individual affective styles in processing emotional stimuli. Gentsch and Synofzik's (2014) affective coding model of agency also indicates that differing affective traits and states influence representations of agency. Moreover, states of depression are known to be accompanied with symptoms which reflect a reduced sense of agency (Ratcliff, 2013). Examining the role of mood on the sense of agency over both neutral and valenced stimuli may therefore clarify the role of affect for agency ascription. This can be examined for instance, using clinical populations or depression severity scales in subclinical populations, or mood induction techniques to examine the role of affective traits and states, respectively.

Applications for the role of affect on the sense of agency

Social interactions play an enormous role in the daily functioning of life and our actions sometimes cause positively or negatively valenced events, or are undertaken whilst in a positive or negative affective state. Elucidating the role that the affective state or consequence has on our construction of agency over actions may have implications regarding our sense of culpability and responsibility. This may have further implications to legal policy and how actions can be seen in the eyes of the law. Moreover, identifying deficits or 'hyper agency' in disease or subclinical populations can act as the first step in remedying the dysfunction in agency, with aim to reducing symptoms of disease. This may be particularly poignant for reducing symptoms of passivity and anhedonia in depression and schizophrenia.

Conclusion

Experiments 7-9 investigated the influence of individual differences in social anxiety and the valence of social emotional action-outcomes on the sense of agency. It was found that positive and negative action outcomes were not cues that modulated the implicit measure of the sense of agency differently. Moreover, levels of social phobia did not modulate the degree of temporal binding over social emotional outcomes. These data therefore failed to support the notion that the construction of agency is influenced by the valence of social emotional actions-outcomes, instead providing boundary conditions in which the sense of agency is robust.. Theoretical and methodological explanations are proposed for the null effects observed here, with suggestions for future research which aims to clarify the role of socially valenced action-outcomes on the sense of agency.

Chapter 8: Discussion

Previous research into the sense of agency using temporal binding measures has predominantly focused on contexts which help or hinder the construction of agency. However, in reality individuals rarely carry out actions in stark laboratory type settings, rather individuals may perform actions which require varying levels of exertion, or under differing types of cognitive strain, such as fatigue and stress, or whilst multitasking. Similarly, being highly social beings, humans often perform actions in social settings, with actions prompting emotional responses of the recipient as a result. Individual differences in personality traits may also account for differences in the way in which agency is attributed across contexts. These important topics have however received little empirical investigation in the field of agency. This thesis therefore aimed to investigate the role of different agency cues in these varying contexts by examining the role of physical and mental effort, the role of individual differences in levels of schizotypy and social anxiety, and the role of social emotional facial valence and gaze orientation on the sense of agency. The aim was to further our knowledge on how the implicit measure of agency may be hindered under these conditions or not, which has further implications in the way in which culpability and responsibility is understood for outcomes to actions that occur in everyday life.

Results overview

To investigate the role of physical effort in the attribution of agency, Chapter 3 presents two experiments that directly manipulate the degree of physical effort experienced during the action. In particular, Experiment 1 examined the role of physical effort that was directly related to the action, i.e the action itself was exertive. Whereas, Experiment 2 examined the role of physical effort that was unrelated to the action, whereby the effort exerted was in the arm contralateral to the arm making the action. Previous research has found that high task-related physical effort, manipulated in the same way as in Experiment 1, resulted in greater temporal binding using the Libet clock method compared with low task-related physical effort (Demanet et al., 2013). These findings were consistent with the hypothesis that a greater will to act under effort gives rise to greater agency judgements (Maine de Biran’s hypothesis, 1805, as cited in Demanet et al.). However, given that physical effort is known to deplete cognitive resources, and that cognitive resources are imperative to generating a sense of agency, it is also possible that high physical effort would result in a reduced sense of agency (Block et al., 2016; Huxhold et al., 2006; Kannape et al., 2014). Indeed, both Experiments 1 and

2 demonstrated that high physical effort regardless of whether it is related directly to the action, or is experienced simultaneous to an effortless action, reduced the implicit measure of the sense of agency, the degree of temporal binding, during conditions of agency. The physical effort manipulation had no effect on conditions in which agency was absent. Interestingly, when the physical effort was experienced in the effector, the effect of reduced temporal binding was dependent on the subjective experience of effort and effort induced fatigue. Such that, the greater the subjective experience of effort, and greater task induced fatigue over time, the stronger the effect of reduced temporal binding under high effort is. These effects were interpreted in terms of cognitive resource depletion induced by the high physical effort manipulation which resulted in a disruption of the generation of the sense of agency.

As well as under physical exertion, individuals also often carryout actions whilst experiencing cognitive load due to, perhaps, stress, fatigue and multitasking. Having determined that physical effort disrupts the implicit measure of agency, an effect believed to be due to the strain physical effort puts on cognitive resources that would otherwise be used for agency ascription, Chapter 4 directly examined the role of cognitive load on the ascription of agency. Previous investigations into the role of cognitive load for the sense of agency found that increased cognitive load reduced explicit agency ratings regarding the concurrent action (Hon et al., 2013). Other indirect studies into the role of cognitive load also identify that for cognitively demanding tasks implicit temporal binding measures indexing agency are reduced (Caspar et al., 2016; Sidarus & Haggard, 2016; Yoshie & Haggard, 2013). It was therefore believed that a direct manipulation of cognitive load would disrupt the generation of agency, resulting in a reduction of temporal binding under agency conditions. Experiments 3 and 4 examined the role of mental effort using a working memory task. The Experiments in Chapter 4 demonstrated that high mental effort concurrent to an action resulted in reductions in the implicit measure of agency. But note that in Experiment 3, whereby the cognitive load manipulation was less demanding under high effort conditions, although the interaction was significant the contrast analysis showed a non-significant trend in this direction. The role of task difficulty was also considered and found to not influence the degree of temporal binding. These results are therefore similar to those found in Experiment 2, whereby the effort exerted was also unrelated to the action itself. Like in Chapter 3, these data were believed to provide evidence for disruptions in agency resulting from limitations in cognitive resources challenging the generation of agency. It must be highlighted, that despite similarities in the effects of physical effort and cognitive load on physical performance and physiological arousal responses (Backs & Seljos, 1994; Beatty, 2008; Boksem et al., 2005; Kahneman, 1973; Mehler, et al., 2009; Zenon et al., 2014), there are differences in how they affect the sense of agency. The current experiments indicate that there is an effect of individual differences in the reported effort levels exerted for physical load tasks which are related to the action on temporal binding. Whereas, this effect was not apparent for physical effort that was unrelated to the action, and for mental effort in the form of cognitive load.

Having determined that burdens to the cognitive resource system, through both physical and mental effort, results in disruption in the ascription of agency in Chapter 5, Experiment 5 aimed to determine whether this effect had a neural signature, examined through manipulating mental effort as in Experiment 4 whilst measuring neural activity using EEG. Previous research has identified two neural components that both index agency and demonstrate a sensitivity to the availability of cognitive resources, the readiness potential and the N1 component. The readiness potential is characterised by increasing negativity preceding an action, and has been found to be attenuated for actions under cognitive load (Baker et al., 2011; Libet et al.,1983; Shibasaki & Hallett, 2006). The attenuation is believed to occur due to the reduced ability to focus on the planning of action execution, caused by cognitive resources being diverted to the mentally taxing task (Baker et al., 2011). The N1 ERP indexes agency such that when an outcome is expected, for instance, by it being self-generated, the N1 ERP time-locked to that event is reduced (Ford et al., 2007; Ford et al., 2013; Horváth et al., 2012; Knolle et al., 2012; Knolle et al., 2013; Kuhn et al., 2014; Martikainen et al., 2005; Poonian et al., 2015; Sowman et al., 2012; Timm et al., 2014). The N1 ERP is also known to reduce under conditions in which the cognitive system is indirectly burdened (Boksem et al., 2005; Caspar et al., 2016). It was therefore expected that the readiness potential and N1 component would be reduced under conditions of agency, and further reduced for high effort manipulations.

Unlike in Experiment 4, and somewhat Experiment 3, the mental effort manipulation in Experiment 5 was not successful in modulating temporal binding, neither on a group level, nor specifically for agency tasks. The N1 component demonstrated the expected responses to the agency manipulations, i.e. attenuated N1 for tones preceded by an action. However, the mental effort manipulation had no effect on the N1 responses. There is however, limited evidence for the role of mental effort attenuating the readiness potential. The data indicated that the event preceding activity was sensitive to the effort manipulation, whereby high effort caused an attenuation of the neural activity preceding both types of first event in the trial, either an action or a tone. These effects were observed at a group level, not specifically for conditions of agency. However, when considering the individual role of task difficulty, under agency conditions (and not under conditions absent of agency) attenuation of the readiness potential was greater for those who found the high mental effort task more difficult. These data were therefore believed to indicate limited support for the disruptive role of cognitive resource limitation on the neural signatures of agency. In particular, the readiness potential was shown to be somewhat disrupted when the cognitive system was burdened, indicating that limited cognitive resources impacts the planning of action execution. It must be noted however, that the degree of neural suppression did not correlate with temporal binding, so further research was suggested to confirm whether an attenuated readiness potential directly impacts the behavioural responses to agency. A novel finding may also have been revealed, such that the level of cognitive load modulated the action preceding neural activity, an effect which was detected at scalp location Cz. The mean amplitude of the action preceding cortical negativity at this scalp location was more negative under high cognitive load compared to low cognitive load. This effect of *un*-attenuated readiness potential under high cognitive load at Cz may be suggestive of evidence towards neural processes and circuitry specifically involved with action planning during conditions of cognitive strain.

Experiment 5 also aimed to examine the role of schizotypy on the effect of mental effort reducing the sense of agency. However, no effect of individual differences in schizotypy were observed. This may have been due to the limited sample size. The role of schizotypy was therefore examined further in Experiment 6 (Chapter 6) investigating the influence of subclinical traits of schizophrenia on the sense of agency in a female (Experiment 6a) and a male (Experiment 6b) sample. Individuals with schizophrenia suffer symptoms that manifest as misattributions of agency (Blakemore et al., 2000; Dapratti et al., 1997; Garbarini et al., 2016; Synofzik et al., 2010). Previous research has demonstrated that clinical cases of schizophrenia show a hyper-binding effect, whereby their temporal binding is exaggerated during conditions of agency compared to healthy controls (Haggard et al., 2003; Voss, et al., 2010). Investigation of the influences of individual differences in subclinical levels of schizotypy on agency has however been less consistent with this effect observed in clinical samples (Dewey & Knoblich, 2014).

However, the measure of schizotypy in Dewey and Knoblich was considered insufficient. Experiments 6a and 6b therefore aimed to clarify the effect of individual differences in schizotypy on the implicit measure of agency. Like in Dewey and Knoblich, no hyper-binding effect was observed. However, in females it was found that those with high levels of schizotypy differentiate temporally less between agency and no agency conditions, compared with those low on schizotypy. Moreover, this differentiation was directly correlated with individual levels of schizotypy. However, it must be noted that although the data generally showed a consistent trend, the effect was limited and not wholly consistent across the entire battery of schizotypy measures administered here. However, in the male sample, no effect of schizotypy on the sense of agency was observed. These data were therefore understood as some limited evidence which indicates that individual levels of schizotypy modulate the ability to distinguish between agency conditions and no agency conditions, an effect found in females only. This effect may be in part caused by an enhanced self-relevance of agentically-unrelated events, which is a symptom often observed in schizophrenia.

Experiment 6 determined that individual differences in schizotypy can influence the implicit index of agency. Because humans are highly social beings, further consideration was therefore given to individual differences in other traits. In particular, the role of social phobia presented itself as an important trait to examine when considering the social context human action-outcome relationships take place in. Chapter 7 therefore examined the role of social emotional facial expression action-outcomes on the implicit measure of agency. The research previously examining the role of socially valenced stimuli for the degree of agency over the actions which caused them has been mixed, with reports of greater temporal binding for positive voices following an action (Yoshie & Haggard, 2013), greater temporal binding for more severe negative outcomes to scenarios (Moretto et al., 2011), and no effect of valenced vocalisations on temporal binding (Christensen et al., 2016). It was therefore considered that social phobia may modulate an effect of social responses to action on agency. Across three experiments in Chapter 7 the role of social phobia was examined for its influence on the sense of agency. Also considered was the role of eye gaze orientation as this is known to modulate cognitive resources and the degree of self-relevance of the response to the agent (Maratos, 2011; N'Diaye et al., 2009; Peers & Lawrence, 2009; Peers, Simons & Lawrence, 2013). This is especially relevant as Chapters 3 and 4 find that reduced cognitive resources disrupt the construction of agency. Moreover, it is believed that the greater the self-relevance of an action-outcome the greater the experience of agency would be. Across all three experiments no effect of the valence of the facial expression outcome on the degree of agency was found. When examining the role of social anxiety, the data was mixed. Experiment 7 found that for positive expression outcomes (happy faces), the degree of temporal binding was modulated by levels of social anxiety, whereby agency over positive faces was enhanced for individuals with high levels of social anxiety. This was contrary to predictions. To examine this effect further, Experiment 8 replicated Experiment 7, however, with the addition of averted gaze conditions (and using disgust faces as opposed to sad faces). Again, a relationship between social anxiety and temporal binding in happy face conditions was observed. However, this effect was in the opposite direction to that in Experiment 7, whereby in Experiment 8 temporal binding was *reduced* for individuals with high levels of social anxiety.

Considering these divergent results, Experiment 9 aimed to clarify the effects observed in Experiments 7 and 8 using an arguably more naturalistic manipulation of *dynamic* gaze orientation (Sato & Yoshikawa, 2004), in which the gaze orientation of the faces shifted during the trial. Under these conditions no effect of social phobia on agency was observed across any of the facial valence and gaze orientation manipulations. Because the patterns of data in Chapter 7 were not consistent, and considering the mixed findings in previous literature examining the role of social outcomes on the sense of agency, it was discussed that the effects observed in Experiments 7 and 8 were not reflective of real effects. Rather, it is believed that this lack in modulation of agency by emotional valence, social anxiety and gaze orientation offer informative boundary conditions as to the contexts the implicit measure of agency is sensitive to.

Limitations

This thesis has focused on the factors to which the sense of agency is sensitive. However, it must be made clear that through using a temporal binding paradigm to implicitly measure the sense of agency, only one component of the sense of agency is truly examined. As discussed in Chapter 1, the sense of agency is comprised of both feelings of agency, which can be measured using temporal binding paradigms, and of judgments of agency, which reflect the explicit certification that ‘one did something’. It is typical of sense of agency investigation using temporal binding methods to only consider this one measure of agency, and not include a measure of explicit ratings of agency. However, recent interest has been focused on how the implicit measure of agency using temporal binging paradigms reflects explicit judgements of agency. Although in usual instances, when there is no confusion over agency ascription, judgements of agency and feelings of agency tend to reflect each other, recently, it has been observed that feelings and judgements of agency can be dissociated. For instance, Dewey and Knoblich (2014) examined the role of neural sensory attenuation, temporal binding and explicit ratings of agency. Interestingly, they find that none of these measures directly correlated with each other. Moreover, although explicit judgments of self agency did not reflect the neural N1 response, it did directly reflect a later component, the P3a, which was attenuated for expected self-initated outcomes (Kühn, Nenchev, Haggard, Brass Gallinat & Voss, 2011). It is therefore suggested that implicit and explicit measures of agency tap into different processes that contribute to the overall sense of agency. Empirical examination of how these measures of agency interact and inform one another to form the overall generation of agency would therefore be informative as to whether implicit and explicit agency are distinct constructs.

As discussed in Chapter 1, the interval reproduction method of temporal binding poses some advantages over the more typically used Libet clock. For instance, interval reproduction measures measure the perceived interval between two events directly, and uses experiential reproduction of experienced intervals as opposed to converting positional judgments into temporal measurements. Thus, there is reduced risk of bias to the interval estimations using the interval reproduction method.

However, as also discussed in Chapter 2, for the interval reproduction method the may be variability in the perception of the beginning of the stimulus interval. In no agency conditions, the onset of the interval between the two events occurs after the first tone, but the participant may perceive the onset of the temporal interval as at the onset of the first tone. In such a case, the interval would be perceived as longer (the actual interval in addition to the duration of the first tone) and may account for some, or all, of the reduced temporal binding effects in no agency conditions compared with agency conditions. This, however, may not be such a limitation as sensible experimental design employed throughout the thesis acts to overcome this. For instance, by employing a 2 x 2 design such that one can compare the effect of one variable across agency and no agency conditions. If a sense of agency is modulated by variable X its effects should manifest in agency conditions only, such as in Chapters 3 & 4 whereby effort modulated temporal binding in agency conditions only. Whereas, if variable X modulates time perception, its effects should manifest across both agency and no agency conditions.

Future directions

It is evident from the findings in Chapters 3 and 4 that cognitive resource availability plays a crucial role in the generation of the sense of agency. These experiments investigated the role of load to working memory to induce the sensation of mental exertion. Other forms of limited cognitive resource availability could be examined in future research, such as the role of stress, fatigue and multitasking. These investigations would have great relevance to real world applications of the effect of mental exertion on our sense of agency. Experiment 5 also highlighted a novel effect in which the levels of cognitive strain experienced may be neurally differentiated, and that this effect is detected using EEG at scalp location CZ. Future work should aim to replicate this effects, and also aim to understand and confirm what is driving this effect theoretically.

The current thesis was also interested only in one component of the sense of agency, namely feelings of agency which are measured using the temporal binding method. Of great importance, however, is how these feelings of agency under the contexts examined here map onto the second component of the sense of agency, explicit judgements of agency. This is especially poignant considering that these components may rely on different mechanisms and thus can under certain conditions be dissociated. This may be particularly true of physical effort manipulations, whereby judgements of agency are expected to be enhanced under high physical effort, whereas high physical effort tasks are found in this thesis to disrupt the measure of feelings of agency.

Similarly, the findings in Chapter 7 indicate that there is no effect of social valence and gaze orientation on the sense of agency, that is, the feelings of agency component. However, one may also expect that judgments of agency may not follow this pattern. Rather, it may be expected that denial of responsibility is more likely to manifest as a result of causing a negative socially valent response. Moreover, declaration of responsibility may be more likely to manifest as a result of a positive socially valent response in instances where agency is unsure of or non-existent. These expected disparities between judgments of agency and the reality of agency may facilitate social interaction and inform the suitability of future behaviour, but may not be captured by the temporal binding measure of agency. The concurrent measure of both feelings and judgments of agency can therefore highlight the weight of importance of each component of agency for the overall sense of agency across contexts.

The role of affect for agency was also only considered in Chapter 7 as the response to an action. The affective model of agency however, identifies that trait or state valence may also impact how responses to our actions are believed to be the effect of our actions (Gentsch & Synofzik, 2014). This is notably observed in illness such as depression, whereby passivity is experienced. Investigation into the temporal binding measure of agency concurrent with examination into state induced valence, using for instance, mood induction techniques, or trait valence using clinical samples, may therefore provide the building blocks with which to understand agency deficits in disorders of negative affect.

Finally, Chapter 6 identified that there is reduced differentiation in the temporal binding across agency and no agency conditions in individuals with high levels of schizotypy. This effect has not been addressed theoretically before. This may be partly due to the type of task employed to measure the sense of agency. Typically, the Libet clock method has been used to investigate the sense of agency in clinical samples of schizophrenia (Haggard et al., 2003; Voss et al., 2010), and for psychosis-like ketamine induced disturbances (Moore et al., 2011; 2013). Typically this does not allow for the interval between the action and the keypress to be compared with a no agency equivalent interval (Moore et al., 2011; Moore et al., 2013; Voss et al., 2010). When such an interval could be compared with a no agency equivalent (Haggard et al., 2003) this effect was statistically observed, but was not approached theoretically. The interval estimation method of temporal binding as a measure for the sense of agency therefore has important implications for further understanding how temporal binding is modulated for individuals with schizophrenia.

Summary

This thesis has examined contextual cues which hinder the generation of agency and weaken the implicit measure of the sense of agency, and also determines some boundary conditions in which the implicit measure of agency remains stable. For instance, for the first time, high physical and mental load has been found to disrupt the implicit measure of agency (Chapters 3 & 4). A direct investigation of cognitive load (Chapter 4) indicted that these effects may be due to a reduction in cognitive resources available for agency generation, suggesting for the first time that feelings of agency rely on cognitive resources to be available. Moreover, despite the unsuccessful modulation of temporal binding, here limited evidence supports the disruptive role of mental effort on the neural response preceding actions (Chapter 5). In particular, those who found the high effort task more difficult produced more attenuated readiness potential, i.e. reductions in the neural signature of the planning of action execution. Mental effort, however, was not found to modulate the N1 neural response to the action outcome. For the first time, it can be suggested with limited evidence, that the action preceding neural activity is disrupted under cognitive strain, although no evidence was found here to imply that this may have an effect on the implicit measure of the sense of agency. This therefore opens itself for replication to provide further clarity regarding this effect.

This thesis also considered the role of individual differences for the ascription of agency. In particular, investigated was the role of schizotypy (Chapter 6) and social anxiety (Chapter 7) was examined. The role of levels of schizotypy was found to modulate the degree at which agency and no agency conditions were temporally differentiated, but this effect was subject to gender differences as this although was found in females, was not consistent in males. Specifically found was that the degree to temporal binding was less distinct across Agency and No Agency conditions for those with high compared to low levels of schizotypy. For the first time, this was theoretically addressed in this thesis. It is believed that individuals with high levels of schizotypy perceive more self-relevance to action-unrelated events, which reflects as the reduced temporal binding between two action-unrelated events. This also reflects symptoms of delusions of reference individuals with schizophrenia experience in which coincidental events are perceived as being significant to the self.

Finally, this thesis addressed the role of individual differences in social anxiety on the sense of agency for the first time, and how the sense of agency may be modulated by social emotionally valent responses to action and affected by gaze orientation (Chapter 7). Contrary to what was expected, across three experiments the findings indicate that the implicit measure of agency is not sensitive to the valence of facial expression responses or gaze orientation. Moreover, although individual differences in schizotypy modulated temporal binding (Chapter 6), individual differences in social phobia did not show a modulatory effect. Chapter 7 therefore provides several boundary conditions which the implicit measure of the sense of agency is not influenced by.

This thesis therefore examined several contexts which may weaken the implicit measure of the sense of agency. The role of factors across the actor-action-outcome relationship were examined, revealing that the role of individual differences in the actor can impact the degree of agency (schizotypy), but can also provide boundary conditions in which individual differences provide no influence on the degree of agency ascribed to an action (social anxiety). Furthermore, the role of the qualities of the action have also proved to hinder the degree of agency ascribed when the act is physically exerting, or when the act is concurrent with physical or mental strain. Finally, the emotional valence and gaze orientation of facial expression responses to actions provide further boundary conditions on which the sense of agency is not dependent.

In this thesis the role of cues that allude to a sense of agency was examined. It was found that there are cues that despite indicating authorship of action can hinder agency construction, there are contexts in which unreliable agency cues are referred to resulting in abnormal constructions of agency, and there are also cues which are not considered at all in the generation of agency. The work of this thesis therefore increases our insight into contextual factors that impact the implicit measure of the sense of agency, and provides boundary conditions in which agency is not influenced. The take home message that should be highlighted considering these findings is that one must be mindful in considering contextual factors when deducing agency, because the construction of self-agency is influenced, perhaps hindered, under certain contexts, and remains robust under other. This provides an opportunity to facilitate how culpability and responsibility for our actions can be understood, with particular relevance to law and criminal justice.

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Appendix 1

Howard et al., (2016)

Physical and mental effort disrupts the implicit sense of agency

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EEH and APB conceived the idea and all authors contributed to experimental design. EEH conducted the experiments and analysed the data. All authors interpreted the data. EEH and APB wrote the manuscript with critical revisions from SGE.

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Abstract

We investigated the effect of effort on implicit agency ascription for actions performed under varying levels of physical effort or cognitive load. People are able to estimate the interval between two events accurately, but they underestimate the interval between their own actions and their outcomes. This effect is known as ‘intentional binding’, and may provide feedback regarding the consequences of our actions. Concurrently with the interval reproduction task, our participants pulled sports resistance bands at high and low resistance levels (Experiments 1 and 2), or performed a working memory task with high and low set-sizes (Experiment 3). Intentional binding was greater under low than high effort. When the effort was task-related (Experiment 1), this effect depended on the individual’s explicit appraisal of exertion, while the effect of effort was evident at the group level when the effort was task-unrelated (physical, Experiment 2; mental, Experiment 3). These findings imply that the process of intentional binding is compromised when cognitive resources are depleted, either through physical or mental strain. We discuss this notion in relation to the integration of direct sensorimotor feedback with signals of agency and other instances of cognitive resource depletion and action control during strain.

Keywords: Sense of agency, temporal binding, intentional binding, experience of effort, time perception.

Physical and mental effort disrupts the implicit sense of agency

It is important that the human motor system can efficiently process events which are the result of its own actions, and to discriminate these from events in the world for which it is not responsible. For instance, if I kick a ball and it knocks over and smashes a vase of flowers, I know my action of kicking the ball was responsible for the vase smashing. Self-authored events like this tend to be easy to identify and this feeling that 'I did it' is known as a sense of agency. Some actions are more effortful than others; kicking a ball as hard as one can might break a vase, but so might brushing one's arm against it as one walks past it precariously positioned near the edge of a table. Both these actions have the same outcome, but might require the action monitoring system to respond differently in order to correctly ascribe agency. Here, we tested the role of physical and mental effort on the ascription of sense of agency, using an implicit measure.

The attribution of agency

Self-agency is detected where there are cues relating to intentionality, volition, predictability and contiguity. An interesting phenomena occurring under these conditions is that actions and their effects are perceived as occurring closer together in time than they did, an effect known as temporal or intentional binding (Barlas & Obhi, 2013; Engbert & Wohlschläger, 2007; Engbert, Wohlschläger, Thomas, & Haggard, 2007; Haggard, Clark & Kalogeras, 2002; see Moore & Obhi, 2012, for a review). One theory of subjective time perception suggests that 'ticks' of an 'internal clock' give rise to our sense of time passing. The pace of this clock varies with arousal and motor activity (Gibbon, Church & Meck, 1984; Treisman, 1963; Wearden Pilkington & Carter, 1999). When the pace of neural 'ticks' slows, durations appear shorter due to the accumulations of fewer pacing 'ticks'. Conversely, when the pace of the 'ticks' quickens, durations appear longer. Contexts characteristic of self-agency are believed to slow the pace of the internal clock as a consequence of motor prediction. This results in the shortening of subjective time and temporal binding (Wenke & Haggard, 2009). This may be an adaptive process to help to create a sense of agency, and in a general sense this process could assist the sensorimotor system to identify and monitor its effects and optimise performance (Buhrmann & Di Paolo, 2015; Wenke & Haggard, 2009).

Several accounts as to how agency is attributed to the self have been suggested, including the forward predictive comparator model (Blakemore, Frith & Wolpert, 2001; Blakemore et al., 2002; Wegner, Sparrow, & Winerman, 2004), the post-hoc inference account (Wegner & Wheatley, 1999), and the optimal cue integration account (Moore & Fletcher, 2012; Synofzik et al., 2010; Synofzik, Vosgerau, & Lindner, 2009; Synofzik, Vosgerau, & Voss, 2013). The comparator model provides a predictive account of agency attribution, characterised by the comparison between predicted action effects with actual action effects. Congruence between these effects results in perceived self-authorship and a sense of agency, whereas incongruence results in diminished sense of agency.

An alternative model, the post-hoc inference account, provides a post-dictive re-constructionist account of agency attribution. Here, sense of agency self-attribution is dependent upon reflection on the action-effect relationship after the outcome has occurred. For instance, when there is an intention to act, when the perceived effects can be explained by the intended action, and when there is no other plausible cause for the effect, sense of agency is then experienced and retrospectively introduced into consciousness. Finally, the optimal cue integration account recognises the importance of both pre- and post-dictive cues. These cues are then weighted for their reliability for agency attribution depending on the context and then used to determine self-authorship. The ability to construct these cues and make comparisons between expected and actual effects of actions may depend on the availability of cognitive resources. Indeed, diminished attentional resources have been shown to impair explicit ratings of agency (Hon, Poh, & Soon, 2013). Moreover, studies concerning cognitive load, kinematics and motor awareness offer support to this prediction. Dual task paradigms employing mental arithmetic, memory tasks and fine motor movements during balance, gait, posture and walking tasks have shown reductions in motor control and motor awareness (Kannape, Barré, Aminian & Blanke, 2014; Lindenberger, Marsiske & Baltes, 2000; Woollacott & Shumway-Cook, 2002). Dual task performance models suggest that motor control and cognitive activity compete for cognitive resources (Huxhold, Li, Schmiedek & Lindenberger, 2006; Lacour, Bernard-Demanze & Dumitrescu, 2008). In such cases motor control and awareness become less efficient due to cross-domain resource competition. The deficits in motor awareness caused by limited cognitive resources are especially of relevance to the sense of agency as, in accordance with the forward models of motor control, it is a crucial factor in the ability to monitor self-initiated actions. This cognitive resource limitation notion therefore has interesting implications regarding the role cognitive resource availability may have on constructing the attribution of agency.

Mental and Physical Effort

We are concerned primarily with how effort might influence the implicit sense of agency. It is important then to note that despite appearing to be independent concepts, physical and mental effort similarly put strain on the cognitive system by expending cognitive resources (Dietrich, 2003; Dietrich & Sparling, 2004; Franconeri, Alverez & Cavanagh, 2013). Mental and physical effort therefore draw from and deplete a common cognitive resource. It is also important to note that exertion influences perception in other domains. For instance, perceived distance increases and hills seem steeper under conditions requiring more physical exertion (e.g. when carrying a heavy load; Bhalla & Proffitt, 1999; Sugovic & Witt, 2013; Witt, Proffitt, & Epstein, 2004). These apparent spatial distortions as a function of required effort are also mirrored for the perception of time.

A recent meta-analysis investigating the effect of physical load on duration judgements revealed that physical workload results in longer perceived durations (Block, Hancock & Zakay, 2016; seven studies spanning from 1963 – 2011). However, the impact of effort on perceived duration need not be experiential, as stimuli that allude to motion, action, or exertion also elongate perceived durations. For example, faster moving non-biological stimuli are perceived to last longer than slower moving stimuli (Brown, 1995; Kaneko & Murakami, 2009), and the perceived duration of images of ballet dancer statues are lengthened when the poses reflected greater levels of exertion (Nather, Bueno, Bigand & Droit-Volet, 2011). The elongation of subjective time as a result of effort are also found for mental activity. Depleted attentional resources and increased cognitive load result in longer retrospective subjective time judgements (for a review see Block, Hancock, & Zakay, 2010). Given these findings highlighting the similarities between the effects of physical and mental effort on time perception, one can hypothesise that physical and mental exertion could have similar disruptive effects on temporal measures of the sense of agency, driven by the depletion of cognitive resources (Dietrich, 2003; Dietrich & Sparling, 2004, Franconeri et al., 2013; Hon et al., 2013).

Sense of agency and effort

Given what we know about the effects of physical and mental exertion on performance and perception, and assuming that ascribing agency is a costly cognitive process, the hypothesis follows that agency should be reduced under conditions of mental or physical effort. There is some support for this hypothesis from a study using an explicit measure, where participants reported the degree to which they felt agency over an event (Hon et al., 2013). These authors found that explicit ratings of agency over a dot that moved following an arrow key press were reduced under conditions of high cognitive load, which was manipulated using a working memory task. This is an interesting finding but converging evidence using an implicit task would be valuable in understanding the processes involved in agency attribution during strain. This is especially important given that explicit and implicit measures are sometimes found to be dissociated (Dewey & Knoblich, 2014; Obhi & Hall; 2011).

Some studies that have used implicit measures lend indirect support to the notion that mental effort disrupts the implicit sense of agency, though their research questions did not directly address the role of cognitive load. Specifically, temporal binding for self-actions has been shown to be weaker when the outcome of the action is socially negative (Yoshie & Haggard, 2013), or when the actor performs the action under coercion (Caspar, Christensen, Cleeremans & Haggard, 2016). Individual ratings of agency over outcomes to actions have also shown to be lower when there is conflict in action selection caused by distractor stimuli (Sidarus & Haggard, 2016). Indeed, each of these acts imply a significant degree of cognitive conflict (see Greene, Nystrom, Engell, Darley & Cohen, 2004), which would make their findings appear broadly in line with our hypothesis.

A general explanation of these effects could be drawn from the effect of resource depletion on time perception. As noted above, subjective time lengthens under load (Block, et al., 2010; 2016), which would result in less temporal binding (i.e. smaller underestimation errors) in agency conditions due to the resources required to bind the action and its effect together already being committed to the cognitively effortful primary task. However, the only research to have directly addressed cognitive effort during the task itself used an explicit measure (Hon et al. 2013), as did the research inducing conflict in action selection (Sidarus & Haggard, 2016). The work by Caspar et al. (2016) and Yoshie and Haggard (2011), although employing implicit measures, manipulated the outcome of, or the motivation for, the action, rather than the effort context under which the action itself was performed. Therefore, a direct test of how effort influences agency using an implicit measure would be valuable in understanding the processes involved in agency attribution during strain, and determining if effort affects interval estimation measures of sense of agency in a comparable way to explicit ratings previous found (Hon et al., 2013).

One recent study has more directly investigated the effect of *physical* effort exerted during the action, using an implicit measure (Demanet, Muhle-Karbe, Lynn, Blotenberg & Brass, 2013).

The pattern of data observed by Demanet et al. (2013) and the conclusion drawn accord with Maine de Biran's hypothesis (1805, as cited in Demanet et al.) that effort is a cue to identify self-agency. This explanation is convincing and a good account of their finding of enhanced temporal binding under effort. Nevertheless, their finding is contrary to what one might predict given that it is known that physical effort depletes cognitive resources, which is associated with time expansion, not compression, and that the depletion of cognitive resources reduces motor control and awareness - elements fundamental for agency ascription (Block et al., 2010; Block et al., 2016; Huxhold et al., 2006; Kannape et al., 2014). Hence, it might be expected that the opposite effect would be observed; that exertion would result in disrupted – not enhanced - intentional binding. If the role of effort in reducing cognitive resources specifically disrupts the ascription of agency – rather than a general disruption of time perception - then it can be expected that effort will not have a similar disruptive effect during a passive control task in which agency is absent. To provide evidence that can help to establish the role of effort in implicit agency, we present three experiments that for the first time to our knowledge investigate the effect of task-related physical effort, and in further experiments, task-unrelated physical and mental effort, on implicit agency attributions.

The current study

To determine whether physical and mental effort modulate agency over actions and their outcomes, a temporal binding paradigm measuring implicit agency was used. In particular, an interval reproduction paradigm, previously demonstrated to successfully show temporal binding in agentic tasks (Buehner & Humphreys, 2009; Engbert, Wohlschläger, & Haggard, 2008; Humphreys & Buehner, 2010; Poonian & Cunnington, 2013), was used here to measure implicit sense of agency. Experiments 1 and 2 investigate the role of task-related and task-unrelated physical effort on agency, respectively. In this way, Experiment 2 is a close replication of Demanet et al. (2013), except that we use an interval reproduction method of intentional binding and they used the 'Libet clock' method. Experiment 3 extends the examination of the effects of effort for sense of agency to the cognitive domain, investigating the role of mental effort in the form of cognitive load, for the ascription of agency. Experiment 3 can be compared with Hon et al., (2013) who investigated explicit measures of agency under varying load.

We believe these studies are the first to investigate the role of task-related physical effort on implicit agency. Moreover, these experiments are the first to investigate the influence of physical and mental effort on sense of agency using the interval reproduction paradigm. Mental effort has also not before been directly investigated for its role in modulating implicit agency. Therefore, these features of our approach and design afford a more direct appraisal of different sources of effort on the implicit sense of agency than has been undertaken previously.

Given the common effects of physical and mental effort depleting cognitive resources, we can predict that high effort will result in a decrease in temporal binding across physical and mental effort in agentic conditions. However, the only previous study to investigate physical effort and sense of agency, found the converse effect, that high effort increased implicit agency (Demanet et al., 2013). Our investigation therefore also aims to clarify whether there is a general effect of effort on agency, or whether the specific context and source of the effort plays a critical role in the extent to which an implcit sense of agency is generated.

Experiment 1: Task-related physical effort

The first experiment was designed to test the effects of task-related effort on implicit sense of agency. Participants made temporal reproductions of intervals between their action (depression of a key) and the consequence (a tone) whilst under low or high task-related physical effort, i.e. the arm under effort was the arm performing the actions and interval reproduction task. If effort acts as a cue that the self is acting in the environment, and therefore increases the sense of agency that the action generates, then greater temporal binding between actions and consequences whilst under high effort are expected. Alternatively, if effort depletes cognitive resources responsible for generating the agency signal, then more effortful actions will produce weaker temporal binding. We also asked participants to provide ratings of the subjective effort they exerted under low and high effort in order to allow us to examine relationships between subjective effort and agency.

Method

The following applies to all three experiments. We report how we determined our sample size and all data exclusions (if any). We also report all manipulations and all measures in each experiment (Simmons, Nelson, & Simonsohn, 2012). Our target sample size for each experiment was n = 36 based on Demanet et al. (2013), who tested a similar research question. We have also calculated that to achieve medium effect sizes (i.e. η_p^2 =

.06, $r = 0.5$, $d_z = 0.5$ at Power = 0.8, $\alpha = .05$), a sample of $n = 32$ was required. Our stopping rule was to aim for $n = 36$, but to stop near that number for convenience at the end of a run of laboratory bookings. We excluded single trials from all three experiments where the participant produced extreme interval reproductions (>3*SD* from the individual's mean). We excluded participants if their mean reproduction errors were >3*SD* from the group mean.

Participants

Thirty-five participants aged 18-51 years (*M* = 22.2 years, *SD* = 7.79; six were men), recruited from the University of East Anglia, completed the experiment in return for payment or course credit. Participants gave informed consent and were naïve as to the research question. Because the experiment involved exertion while holding a latex exercise band, individuals with a latex allergy, or back, neck, arm or shoulder pain were excluded from participation. No participants met these exclusion criteria. The study was approved by the School of Psychology Research Ethics Committee, University of East Anglia.

Apparatus & Stimuli

Physical effort was manipulated using Thera-Band® latex resistance bands which are typically used for exercise. The levels of effort were operationalised using two different resistance bands. This allowed for Low and High effort conditions using Thera-Bands® in colours yellow and blue, respectively. The amount of force required to hold the bands in the required position was approximately 24.5N and 4.9N for the high and low effort bands, respectively. The bands were attached to a handrail that was fixed to the wall behind the participants, 94cm from the ground, positioned off to the right so that the band was pulled past the participant's trunk and held in the right hand over the space bar.

The position of the keyboard from the center of the space bar was approximately 40 cm from the front edge of the table. The height of the table was 71 cm. A tone (150ms, 440Hz; created using Audacity® software) was presented using Logitech speakers. Visual stimuli were presented (black text on a white background) using *E-Prime*® software on a Dell 1909W monitor (size: 19 inches; resolution: 1440 x 900; refresh rate: 60 Hz).

Design

In a 2x2 repeated subjects design participants completed four experimental block types differing across two factors: Presence of Agency (Agency and No Agency) and Physical Effort (Low and High). The dependent measure was duration reproduction error, derived as the actual interval minus the reproduced interval (ms). Participants also rated how much effort they experienced whilst holding the low and high effort bands in the required position both before (Pre) and after (Post) the experimental blocks (scale from 1-10; 1 indicating low effort).

Procedure

Presence of Agency manipulation. Instances of agency were manipulated using an Interval Reproduction task (Humphreys & Buehner, 2010; Poonian & Cunnington, 2013) in which participants were instructed that a tone would occur after a first event: either a self-initiated spacebar press with their index finger (Agency) or after a first auditory tone (No Agency). The stimulus interval was the delay between the first event and the outcome (randomised between 500-1500ms; as in Humphreys & Buehner, 2010; Poonian & Cunnington, 2013). Participants were immediately prompted to make response intervals by depressing the spacebar with their index finger for the duration they perceived the stimulus interval to have lasted, after which a fixation cross was presented for 1000 ms and the trial ended (see Figure 1 for the Interval Reproduction task procedure).

FIGURE 1 ABOUT HERE

Effort manipulation. Throughout the interval reproduction task the level of physical effort was manipulated by having participants hold the end of a resistance band (Low or High) with their right hand, in a fixed position with their arm outstretched towards the spacebar which sat approximately 40cm from the table edge. This allowed for *task-related* induction of effort (we investigate task-unrelated effort in Experiment 2; see Figure 2 for the effort manipulation set-up). Participants were instructed before each block of trials as to which band to hold. After each block participants were encouraged to take self-paced rest periods.

FIGURE 2 ABOUT HERE

Before starting the experiment participants completed a short practice block involving the Presence of Agency and Physical Effort manipulations. The experiment consisted of eight blocks (two blocks per condition) of 20 trials per block. Each experimental condition therefore contained 40 trials. Condition order, manipulated across blocks, was counterbalanced so that one block of each condition was presented in the first half (blocks 1-4) and the second half of the experiment (blocks 5-8). The blocks in the first half of the experiment were counterbalanced with each possible order run through. The blocks in the second-half backwards mirrored the condition order in the first half. The experiment comprised 160 trials and typically took approximately 45 minutes.

Effort manipulation check. The effort manipulation was successful. This was confirmed by examining the effort ratings that participants gave to each band before and after the experiment in a 2 (Physical Effort; Low and High) X 2 (Time; Pre and Post) ANOVA. The main effect of 'Physical Effort' was significant, $F(1, 34) = 522.76$, $p < .001$, $\eta p^2 = .94$, due to higher effort ratings for the High compared with the Low effort resistance band (*M* = 6.83, *SD* = 1.38 and *M* = 2.26, *SD* = 0.71, respectively). The main effect of 'Time' was non-significant, $F(1, 34) = 1.4$, $p = .25$, $\eta p^2 = .04$. The interaction was significant, $F(1, 34) = 33.18$, $p < .001$, $\eta p^2 = .49$, because the difference in ratings between high and low effort bands was larger after, compared with before, the experiment (Low effort band: Pre: *M* = 2.49, *SD* = 1.01; Post: *M* = 2.03, *SD* = .82; $t(34) = 2.31$ $p = .027$, $d_z = 0.39$; High effort band: Pre: *M* = 6.43, *SD* = 1.46; Post: *M* = 7.23, *SD* = 1.46; $t(34) = 4.91$ $p < .001$, $d_z = 0.83$).

Results

Trials with extreme reproduction errors were removed (0.48% of trials). Mean reproduction errors for each participant in each condition (see Figure 3) were analysed using a 2 (Presence of Agency) X 2 (Physical Effort) ANOVA, revealing significant main effects of both of these factors: $F(1, 34) = 54.54$, $p < .001$, $\eta p^2 = .62$, and $F(1, 34) = 14.43$, $p = .001$, $\eta p^2 = .3$, respectively. These main effects were due to larger reproduction errors - more underestimation - in the Agency condition than the No Agency condition, (M = -322 ms, *SD* = 236 and *M* = -56ms, *SD* = 265, respectively). This replicates the basic temporal binding effect (Buehner & Humphreys, 2009; Haggard et al., 2002; Humphreys & Buehner, 2010; Poonian & Cunnington, 2013). There were larger reproduction errors in the 'low' effort compared with 'high' effort conditions, M = -208 ms, *SD* = 230 and *M* = -170 ms, *SD* = 228, respectively. However, the critical interaction was non-significant, $F(1, 34) = 2.12$, $p = .154$, $\eta p^2 = .06$.

FIGURE 3 ABOUT HERE

Although the interaction – critical to our research question – was non-significant, we nevertheless performed two planned contrasts to investigate the nature of effects across Presence of Agency and Physical Effort. In the Agency condition, reproduction errors were significantly larger under Low than High effort, $t(34) = 3.46$, $p = .001$, $d_z = 0.589$, while this effect was not significant in the no agency condition, $t(34) = 1.59$, $p = .122$, $d_z = 0.27$. Therefore, due to a non-significant interaction, the overall results do not support our hypothesis that reproduction errors in agency tasks would be reduced under greater physical effort.

As a supplementary analysis, we considered that individual susceptibility to the effort manipulation may play a critical role in determining the extent to which task-related effort might influence the implicit sense of agency. We therefore firstly determined the difference in effort ratings that participants gave to the low and high effort bands (averaged over ratings they gave pre- and post-experiment). Therefore, people who experienced a great deal of difference between how much effort they required to extend the high-effort band versus the low-effort band would have a high Effort Differential score, whereas people who felt that both bands required relatively similar exertion to maintain the extended position would have a low Effort Differential score. We examined whether this Effort Differential measure correlated with the Reproduction Error Differential: the difference in temporal binding between agency and no agency conditions under high vs. low effort conditions (i.e. [Agency High – No Agency High] – [Agency Low – No Agency Low]). A Pearson correlation revealed a significant positive relationship between the two variables, $r(33) = .523$, $p = .001$ (see Figure 4), whereby as Effort Differential increases, so does Reproduction Error Differential. This correlation is also significant if we only consider the post-experiment ratings ($r = .436$, $p = .009$). This means that only participants who felt the difference in effort they were exerting also showed an effect of effort on the implicit measure of agency. Overall, therefore, although the key interaction in the analysis was non-significant, this correlation clearly shows that this was related to the individual perception of the effort itself.

FIGURE 4 ABOUT HERE

Finally, we briefly report here a further analysis prompted by a reviewer (whom we thank for the suggestion), indicates an important role of duration of effort on agency. Specifically, we found that the reduction of temporal binding under high effort was stronger during the second half of trials (i.e. after the arm had been under strain for some time) than in the first half. This finding was supported by the outcome of a 3-way ANOVA with Presence of Agency, Effort, and the new factor Time on Task (1st half of trials vs. 2nd half of trials) as within-subject factors. The critical three way interaction was significant, $F(1, 32) = 5.73$, p =.023, $\eta p2$ = .152. Next, to confirm the source of this 3-way interaction, we conducted 2-way ANOVAs on the two halves separately. The 2-way interaction was not significant during the 1st half of trials, $F(1, 33) = 1.39$, p =.248, *ηp2* = .04 (like in the overall analysis above). However the interaction was significant for trials in the 2nd half of the experiment, $F(1, 32) = 4.473$, $p = .042$, $\eta p2 = .123$. This was due to reduced reproduction errors under high effort compared with low effort in Agency conditions, $t(33) = 4.52$, $p < .001$, $dz = 0.78$ ($M = -354$. $SD = 274$ and $M = -260$, $SD = 283$, respectively). In No Agency conditions this effect was not observed, $t(33) = 1.38$, $p = .177$, $dz = 0.24$ ($M = -47$, $SD = 286$ and $M = -24$. $SD = 287$, respectively. It therefore appears that the effect of high effort on temporal binding increases with time on task.

Discussion

Overall, the data indicate agency effects in that there was greater temporal binding during conditions in which agency was present, replicating previous work (Buehner & Humphreys, 2009; Engbert & Wohlschläger, 2007; Engbert et al., 2007; Haggard et al., 2002; Humphreys & Buehner, 2010). However, there was no reliable difference in the effect of agency on interval reproduction errors across different levels of effort. Nevertheless, although the critical interaction was indeed non-significant, the contrast between effort levels in agency conditions was significant, but in the opposite direction to that found by Demanet et al. (2013). Specifically, there was stronger binding (which implies greater implicit sense of agency) under low effort than under high effort. This discrepancy with Demanet et al's finding could be explained by the difference in how implicit agency was measured. We used the interval reproduction paradigm, whereas Demanet et al used the Libet clock method. However, it is not clear what aspect of these two methods might result in such divergent findings. Another key difference between our procedure and that of Demanet and colleagues is that the present Experiment 1 involved the participants engaging in task-related effort (the hand used to act was under strain) whereas a passive arm was under strain in Demanet et al. In Experiment 2 we test whether this latter difference accounts for the disparate findings by having our participants engage in task-unrelated effort, like Demanet and colleagues' participants.

Although the critical agency by effort interaction did not approach significance at the group level, we did find a significant medium-sized effect when investigating individual appraisals of exertion. Participants who experienced the high effort manipulation as much more exertive than the low effort manipulation demonstrated a larger disparity in binding difference across the low and high physical effort conditions. We also found a medium-sized effect when investigating the build-up of fatigue, such that in the second half of the experiment temporal binding was reduced under conditions of agency under high effort. Therefore, we are able to draw reasonably strong conclusions from these data overall despite the lack of a clear effect at the group- and full session-level; high effort did indeed reduce the sense of agency, but only for participants who registered the exertion as more effortful than the low effort condition, and also in the second half of the experimental session, after fatigue from the effort had set in. Therefore, we are able to draw reasonably strong conclusions from these data overall despite the lack of a clear effect at the group-level; high effort did indeed reduce the sense of agency, but only for participants who registered the exertion as effortful, or after the build-up of fatigue. We note again here, that these findings are in the context of task-related physical effort, so it is important to establish whether these effects (in particular the individual differences effect) are specific to task related effort. Therefore, in addition to testing conditions closer to Demanet et al. by using task-unrelated effort, Experiment 2 also allows us to examine again the influence of individual-level experience on the modulatory impact of effort on the sense of agency.

Experiment 2: Task-unrelated physical effort

Experiment 2 aimed to investigate whether modulations of temporal binding by effort are limited to task-related effort (Experiment 1) by making the effort in this experiment unrelated to the interval reproduction task performance. To do so, participants in this experiment held the band with the hand contralateral to the hand carrying out the interval reproduction and agency task. If temporal binding is affected by general experience of physical effort, that need not be undertook as a necessary part of the action creating the cause-effect outcomes in the environment, then we expect to observe results similar to Experiment 1. That is, high task-unrelated effort reduces temporal binding between action and effect. Alternatively, if there is something action-specific about the nature of the effort – task-related compared with task-unrelated – then we may instead show a reverse pattern and replicate Demanet et al.'s (2013) finding of greater binding under high effort.

Method

Participants

Thirty-five participants (7 men; age range 18-54, *M* = 21.26, *SD* = 6.28) recruited from the University of East Anglia, completed the experiment in return for payment or course credit. Participants gave informed consent and were naïve as to the research question. As the experiment involved exertion while holding a latex exercise band, individuals with a latex allergy, or back, neck, arm or shoulder pain were excluded from participation. No participants were excluded from participation due to this criteria.

Apparatus, Design and Procedure

The only alteration compared with Experiment 1 was that the resistance band was held in the left hand to allow for task-unrelated physical effort. Participants still responded to the interval reproduction task with their right hand, as in Experiment 1. The band was attached to a handrail fixed to the wall 94 cm from the ground on the left hand side of the participant. The band was pulled with the left hand towards the left side of the keyboard until the wrist was in line with the spacebar. The band was held in this position for the entire block of trials (see Figure 2 for effort manipulation set-up).

Effort Manipulation Check. The effort manipulation was successful, as confirmed by the same analysis as in Experiment 1. The main effect of 'Physical Effort' was significant, $F(1, 33) = 251.97$, $p < .001$, $\eta p^2 = .88$ (High: $M = 5.97$, $SD = 1.47$; Low: $M = 2.02$, $SD = .68$). The main effect of Time was significant, $F(1, 33) = 5.8$, $p = .022$, $\eta p^2 = .15$, because effort ratings were higher after than before the experiment (M = 4.18, $SD = .91$; $M = 3.81$, $SD = 1.06$, respectively). The interaction was also significant, $F(1, 33) = 21.83$, $p < .001$, $\eta p^2 = .4$, because the difference between high and low effort ratings was larger after the experiment than before (High: $t(33) = 4.12$ $p < .001$, $d_z = 0.71$; Post $M = 6.38$, $SD = 1.52$, Pre $M = 5.56$, $SD = 1.64$; Low: $t(33) = .55$ $p = .59$, $d_z = 0.1$; Post $M = 1.97$, $SD = .8$, Pre $M = 2.06$, $SD = .85$.

Results

A total of 0.55% of trials were removed as outliers. One participant was further removed for having extreme mean reproduction errors. The remaining data were submitted to the same analysis as in Experiment 1 (see Figure 3). This revealed a main effect of Presence of Agency, $F(1, 33) = 65.98$, $p < .001$, $\eta p^2 = .67$, with larger reproduction errors during Agency compared with No Agency conditions (M = -273 ms, SD =189, and M = 24 ms, SD = 252, respectively). The main effect of Physical Effort was also significant, $F(1, 33) = 5.03$, $p = .032$, $\eta p^2 = .13$, with smaller reproduction errors under High than Low effort (M = -106 ms, SD = 205; M = -143 ms, SD = 198, respectively). Critically, and unlike Experiment 1, the interaction between these factors was also significant, $F(1, 33) = 4.16$, $p = .049$, $\eta p^2 = .11$. Planned contrasts revealed that in No Agency conditions there was no difference between the effort conditions under No Agency, $t(33) = .62$, $p = .542$, $d_z = 0.11$. Whereas, in Agency conditions High effort resulted in smaller reproduction errors compared with Low effort, $t(33) = 2.94$, $p = .006$, $d_z = 0.5$.

Similarly, to Experiment 1, we tested whether the difference between the effort participants stated that they exerted in the high vs. low effort conditions was related to the increase in binding difference between agency and no-agency conditions in the low effort condition relative to the high effort condition. The correlation was not significant whether the mean of the pre- and post-experiment ratings were used, $r(32) = -.147$, $p = .407$, or only the post-experiment ratings ($p = .33$). This stands in stark contrast to the findings of Experiment 1 where there was a moderate and significant relationship between the two variables, whereby the effect of effort on implicit agency was related with the explicit ratings of exertion. The correlation coefficients from Experiment 1 ($r = .523$) and Experiment 2 ($r = -.147$ differ significantly from one another ($z = 2.89$, $p = .004$).

As in Experiment 1, we investigated the effect of the factor 'Time on Task' to compare performance in the first half of the session with the second half. The three-way interaction was non-significant, $F(1, 33) = 1.41$, $p = .24$, $\eta p2 = .041$, indicating that unlike Experiment 1, the effect of effort on temporal binding was consistent through the experimental session.

Discussion

We again replicated the general finding of temporal binding under conditions of agency (Buehner & Humphreys, 2009; Engbert & Wohlschläger, 2007; Engbert et al., 2007; Haggard et al., 2002; Humphreys & Buehner, 2010), and this effect was weaker under high effort, even though the effort was task-unrelated. In Experiment 2, this effect of effort on binding was reliable at the group level (i.e. the critical effort by agency interaction was significant), but there was little role for individual appraisal of the subjective effort required, and was constant across the session, unlike in Experiment 1. Notably, our data are in the opposite pattern to that observed by Demanet et al. (2013).

In Experiment 3, we aimed to explore whether the effect we observed in Experiment 2 would replicate under conditions of a different type of effort, where no physical strain is required whatsoever. Instead, we note that the cognitive system is depleted similarly under physical and mental effort, and at least with our data, the effect of effort appears to be not completely action-specific. Therefore, we predict that high mental effort tasks will result in reduced binding in agency conditions, compared with low mental effort, replicating Experiment 2.

Experiment 3: Mental effort

In this experiment, participants were exposed to high and low levels of cognitive load, using a working memory task whereby items (2 or 8 for low and high effort levels, respectively) had to be kept in working memory during the stimulus interval and reproduction of this interval (adapted from Sternberg, 1966). If we again find that temporal binding is reduced under high (cognitive) effort, it would suggest that implicit sense of agency is vulnerable under conditions of effort, regardless of the source. This would mirror the data of Hon et al. (2013) who found a similar pattern using an explicit ratings task.

Method

Participants

Thirty-six participants (6 men; age range 18-29, *M* = 20.39 *SD* = 2.05) recruited from the University of East Anglia, completed the experiment in return for payment or course credit. Participants gave informed consent and were naïve as to the purpose of the experiment.

Apparatus and Stimuli

Experiment 3 examined the effect of cognitive load on temporal binding. To manipulate this, randomly selected letters (vowels and ‘y’ excluded, Arial font, font size 36, presented in white on a black background at encoding stage, and yellow font presented on a black background for probe letters) served as additional stimuli as part of the Sternberg (1966) memory task. Physical effort was not manipulated so the resistance exercise bands were not used in this experiment. Participants were tested in a group lab up to four participants at a time, but were separated in booths with no access to each other during the task. Stimuli were presented on a BenQ monitor (size: 24 inches; resolution: 1920 x 1080 refresh rate: 60 Hz) Auditory stimuli were presented using Sony 7506 headphones. The Adult Empathy Quotient (Baron-Cohen & Cartwright, 2004) was also administered at the end of the testing session as part of a pilot study for an unrelated research question and so is not discussed further.

Design

In a repeated subjects design participants completed four experimental block types differing across two factors: Presence of Agency (Agency and No Agency) and cognitive load under the factor Mental Effort (Low and High). Sense of agency was measured, as in Experiments 1 and 2, as reproduction errors (calculated as the subtraction of stimulus intervals from response intervals). Reproduction Error Differential was calculated as in Experiments 1 and 2. During the Mental Effort manipulation, memory accuracy performance was recorded, from which an Accuracy Difference was calculated as accuracy score (percentage accurate) under Low Mental Effort minus accuracy score under High Mental Effort.

Procedure

Effort manipulation. Mental effort was manipulated using the Sternberg (1966) Memory task, adapted to administer Mental Effort under Low and High levels of cognitive load. The Memory task consisted of an encoding stage, a maintenance period, and a recall stage. During the encoding stage a series of randomly selected letters were presented successively for 1000 ms each. For Low and High Cognitive Load conditions two and eight letters, respectively, were presented at the encoding stage. The Interval Reproduction task served as the maintenance period, which was followed by the recall stage. The recall stage consisted of a probe letter to which participants distinguished whether or not (pressing '1' and '2', respectively) the probe was present at encoding, which was the case in 50% of trials (at random).

Presence of Agency manipulation. Agency was manipulated as in Experiments 1 and 2, using an Interval Reproduction task. Before starting the experiment participants completed a short block practicing the Presence of Agency and Mental Effort manipulations. Each experimental condition contained 36 trials which were presented in two blocks of 18 trials each. Blocks were separated by a self-paced rest period. The order of block type was counterbalanced as in Experiments 1 and 2. At the end of each block participants were encouraged to take an unrestrained rest period. The full experiment lasted approximately 45 minutes (see Figure 5).

FIGURE 5 ABOUT HERE

Cognitive Load Manipulation Check. Accuracy data percentages were analysed across the two factors (Presence of Agency and Mental Effort) using a 2 X 2 ANOVA. A main effect of Mental Effort was observed, $F(1, 33) = 176.06$, $p < .001$, $\eta p^2 = .84$, because participants recalled more accurately under low compared to high load (M = 92.28%, *SD* = 5.9, and *M* = 72.39%, *SD* = 7.4). Neither main effect of Presence of Agency, nor the interaction between the two factors were significant, *F*'s<1.

Results

Data from one participant were removed because they omitted to perform responses during the working memory task. Trials with extreme reproduction errors were removed (0.54% of trials), as were trials in which responses in the recall stage were inaccurate (17.5%). One additional participant produced extreme interval reproduction scores and therefore was not submitted to further analysis.

Mean reproduction errors for each participant in each condition were submitted to a 2 (Presence of Agency) X 2 (Mental Effort) ANOVA, which revealed a significant main effect of Presence of Agency, $F(1, 33) = 69.74$, $p < .001$, $\eta p^2 = .68$), whereby Agency tasks had greater reproduction errors than No Agency tasks (M = -215 ms, *SD* = 253 and *M* = -22 ms, *SD* = 323 ms, respectively). There was no main effect of Mental Effort, $F(1, 33) < 1$, but the interaction was significant, $F(1, 33) = 4.56$, $p = .04$, $\eta p^2 = .12$.

Planned contrasts examined the interaction revealing that for No Agency tasks there was no effect of effort, $t(33) = .88$, $p = .39$, $d_z = 0.149$**.** However, for Agency tasks an effect of Mental Effort was observed, $t(33) = 2.1$, $p = .044$, $d_z = 0.36$, whereby reproduction errors were greater under Low effort (see Figure 3).
In this experiment, we did not ask participants to provide ratings of how much effort they exerted under high and low effort. Instead, we have the objective measure of their performance as a proxy for effort. That is, an individual's difference in accuracy between the high and low cognitive load conditions can be used as an index of how much more taxing the high load task was relative to the low, for each individual. Like before, this was correlated with the difference in the effect of agency between the high and low effort conditions. The correlation was not significant, $r(33) = -.113$, $p = .523$, and was significantly weaker than the significant positive correlation from Experiment 1 ($z = 2.73$, $p = .006$). As in Experiments 1 and 2, we compared the performance on the first and second halves of the experiment with the factor 'Time on Task'. The three-way interaction was non-significant, $F(1, 33) < 1$, meaning that the effect of effort on agency was consistent across the experiment session.

Finally, we report here for completion a preliminary experiment we conducted before we ran Experiment 3. This differed from Experiment 3 in that the high load condition was not as taxing, using only a set size of 6 instead of 8. With this lower high set size, the critical effort x agency interaction was also significant, as in Experiment 3, $F(1, 35) = 5.0$, $p = .03$, $\eta p^2 = .13$, due to a weaker effect of agency under the high load condition. However, the contrast comparing temporal binding in the agency conditions did not differ significantly between high (-194ms) and low (-220ms) load ($p = .12$). We interpreted this as limited evidence for reduced implicit agency under cognitive load, and this motivated us to test a higher load level (8), which we presented here in full as Experiment 3.

Discussion

Experiment 3 aimed to determine effort effects in action-unrelated cognitive load on temporal binding. In addition to the basic temporal binding effect under conditions of agency, an interaction with effort was also observed. In conditions in which agency was present, high mental effort decreased temporal binding compared with low mental effort conditions. This effect of mental effort was not observed in conditions in which agency was absent. These effects on temporal binding therefore reflect those found for both action-related and –unrelated physical effort (Experiments 1 and 2, respectively). As in Experiment 2, here there was no modulatory role the individual experience of effort, nor of time on task, on the effect of effort on temporal binding. Taken together, the data we have collected using the cognitive load task shows that mental effort reduces temporal binding under conditions of agency, which is in line with that observed using explicit measures (Hon et al., 2013).

General discussion

The current study investigated the role of both physical and mental effort for the modulation of implicit sense of agency. Using an interval reproduction paradigm, the amount of temporal binding between events in an agentic context (a self-made action and a consequent tone) compared with events which were not agentically related (two tones), was measured. Interval reproductions that are shorter than the actual length of the interval represent temporal binding between the events, whereby the events are perceived as closer together - ‘bound’ - in time. This measure is thought to be a valid implicit measure of the degree of agency that the cognitive system ascribes to a given event (Engbert & Wohlschläger, 2007; Engbert et al., 2007; Haggard et al., 2002; Moore & Obhi, 2012). In each experiment, we found temporal binding under conditions of agency, but not under passive conditions, replicating prior work (Buehner & Humphreys, 2009; Engbert & Wohlschläger, 2007; Engbert et al., 2007; Haggard et al., 2002; Humphreys & Buehner, 2010; Moore & Obhi, 2012). Of critical interest was whether task-related (Experiment 1), task-unrelated (Experiment 2) and mental (Experiment 3) effort would modulate this effect of agency on temporal interval reproduction.

Overall, our data revealed that in conditions of agency temporal binding was weaker under high, compared with low effort (however, note that for Experiment 1, the key interaction was non-significant). This effect was not observed for conditions absent of agency. In general terms, this effect was consistent across experiments and statistical effect sizes were medium for the key interactions and correlations (Experiment 1 – key correlation r = .52; Experiment 2 – key interaction η_p^2 = .11; Experiment 3 - key interaction η_p^2 = .12) and small to medium for the key contrasts (Experiments 1-3 d_z's 0.26, 0.50, 0.36, respectively). It is also worth noting that the key interactions in Experiments 2 and 3 reached the conventional .05 *p*-value threshold by rather small margins, which suggests that although our sample size was calculated as sufficient to reveal the predicted effect sizes, future replication attempts may benefit from a larger sample to detect and confirm these small to medium statistical effect sizes.

Potential mechanisms for reduced sense of agency under effort

Here we found that high effort resulted in a perceived shortening of the time between actions and their consequences (in Experiment 1 this effect is modulated by the subjective experience of effort). Importantly, this effect was not observed for conditions in which agency was not present. A commonality across each of our experiments is that we can assume that in the high load conditions, they either directly (Experiment 3) or indirectly (Experiments 1 and 2) draw on cognitive resources (Block et al., 2016). If we assume that agency ascription is itself cognitively costly, for reason we explain below, then under conditions of compromised cognitive resource availability, such as high effort, temporal binding would be weaker. This would be because there are less resources to dedicate to agency signal generation due to resource depletion during effort exertion. This would explain our data from Experiments 2 and 3, and somewhat the data from Experiment 1. Indeed, such reductions in temporal binding have been previously observed in conditions characteristic of cognitive conflict, such as coercion and negative social emotional consequences (Caspar et al., 2016; Yoshie & Haggard, 2013).

Dual process accounts of cognitive and motor control also lend indirect support for this cognitive resource competition theory for sense of agency (Huxhold et al., 2006; Lacour et al., 2008). Cognitive loading causes a reduction in balance and movement accuracy due to limited cognitive resource availability for motor awareness (Kannape et al., 2014; Lindenberger et al., 2000; Woollacott & Shumway-Cook, 2002). According to internal forward models of motor control, self-agency over an action occurs when motor predictions of the action and sensory consequences match (Blakemore et al., 2001; 2002). We propose that reductions in motor awareness caused by limited cognitive resources, disrupt the ability of the system to create accurate predictions concerning sensory effects and outcomes of willed actions. This then results in a diminished sense of agency. Therefore, when cognitive resources are challenged, in the current case, by mental or physical strain, resources are less available to generate accurate motor awareness, which in turn disrupts the ascription of self-agency. The reduction of temporal binding under high effort in agency conditions in our experiments may be demonstrative of this mechanism.

Action-specific effort effects

Overall, our data suggest that there may be a general effect of effort on implicit sense of agency, whereby high effort reduces temporal binding. However for action specific effort (Experiment 1) this effect is dependent on the subjective experience of effort and effort induced fatigue. That is, for those under task-related effort, we find that the more effort experienced, either for individual differences in subjective effort experienced, or for task induced fatigue over time, the stronger the deleterious effect of high effort is on temporal binding. This modulation of individual appraisals of effort may endorse the cognitive resource depletion account that we suggest. Whereby, high effort, or - in the case of Experiment 1 - those who experience the action specific effort as highly effortful, depletes cognitive resources otherwise used for enhancing motor awareness and therefore disrupts agency ascription and temporal binding (Blakemore et al., 2001; Blakemore et al., 2002; Kannape et al., 2014; Lindenberger et al., 2000; Woollacott & Shumway-Cook, 2002). Subjective task difficulty has been shown to be related to effort expenditure (Ennis, Hess & Smith, 2013). Those who experienced the high task-related effort as less effortful would require less cognitive resources to maintain the effort manipulation. In these individuals, cognitive resources are available for motor awareness and agency ascription. This account explains both the correlation between the effect of effort on binding and the subjective experience of effort, and also the effect of time-on-task in Experiment 1. Interestingly, this effect is not observed in task-unrelated physical or mental effort. To explain this, we consider that when under task-unrelated effort, the effort manipulation may have an indirect but strong effect on the efficiency of the mechanism by which agency is ascribed which outweighs the role of individual experience of effort. This effect could be due to the dual task demands of processing the effort manipulation with one effector, and the action with another (Experiment 2), which could be more demanding than processing input from a common source as in Experiment 1 (cf. Kahneman, 1973; Pashler, 1994).

Limitations and future work

This investigation into the role of effort on sense of agency was in part designed to complement the work of Demanet et al. (2013). However, we found the opposite pattern of results compared with their study. Demanet et al. found that high task-unrelated effort resulted in greater temporal binding compared with low effort with the explanation that the sensation of effort acts as a cue inferring self-agency resulting in greater temporal binding. Demanet et al. used the 'Libet clock' method whereas we used interval reproduction as the implicit measure of agency. It is possible that the differences in the pattern of results may be due to methodological differences. The interval reproduction method captures the temporal relationship between the action and consequence and reflects the slowing of an internal clock (Wenke & Haggard, 2009), whereas the 'Libet clock' method captures the temporal positioning of either the action or consequence, and not the relationship between those two events, so reflects shifts in event perception. Although, it is not completely clear how these two methods would produce divergent results, so it is important that future work pursues this empirical question.

Other work has indirectly investigated the role of cognitive resources on temporal binding as a measure for an implicit sense of agency, finding opposite effects in line with Demanet et al. (2013). Haggard and Cole (2007) investigated the role of focused attention on temporal binding. In the study participants' attention was directed to one of two events, either towards the key press action or - in other trials - to the consequent tone. They found that focused attention on one event resulted in a perceptual event shift in a manner reflecting temporal binding that was stronger for the attended event. Another study that indirectly manipulated cognitive load also found increased temporal binding when the number of action choices was greater (Barlas & Obhi, 2013). The key differences between these two studies and ours are that we aimed to directly manipulate mental effort exerted during the task overall, and moreover, our manipulation was unrelated to the pertinent action, whereas Haggard and Cole directed mental effort to different aspects of the task itself, and Barlas and Obhi manipulated the difficulty of the task. Both these papers showed the opposite of what we report. However, we also note that Hon et al. (2013) showed that explicit agency is reduced – like our present finding with implicit agency – using a similarly non-task-focused manipulation of mental effort. It is therefore likely that the effect of mental effort on agency may critically depend on the source of the cognitive load. The current study did not asses hand dominance or individual levels of strength. These issues could be looked at in order to personalise and equivalate across effectors in investigations of task-related and unrelated physical effort.

Future work could investigate the neural processing of events under conditions of agency and without agency while manipulating effort. The N1 event-related potential is suppressed in response to events that the participant themselves has caused (Caspar et al., 2016; Poonian, McFadyen, Ogden & Cunnington, 2015). This suppression is thought to index sense of agency due to top-down motor predictions causing a suppression of the processing of the effects of actions (Gentsch, Kathmann & Schutz-Bosbach, 2012). It is possible that under cognitive or physical strain, this neural marker for agency could be attenuated (i.e. less N1 suppression). Indeed, under conditions that are arguably high in cognitive conflict (and therefore load), the N1 suppression is weaker (e.g. under coercion, Caspar et al., 2016).

Everyday life consists of effortful actions, fatigue, strain, stress and multitasking. The current study suggests that individuals under these conditions may feel an impaired sense of agency for their actions. This could have implications for moral decision making and responsibility, especially in environments in which cognitive resources are challenged (Caspar et al., 2016). For instance, the feeling of responsibility for actions that lead to accidents may reduce under conditions of fatigue and stress. Indeed, this could be one mechanism by which the action monitoring system itself fails to provide adequate action control under fatigue/stress, leading to erroneous or negligent acts. This notion could have further implications for how the law manages responsibility for actions in the context of mental and physical fatigue.

Finally, we consider the relationship between explicit and implicit measures of agency. We did not measure explicit agency ratings in this study. However, previous work has noted that high effort actions are associated with a greater feeling of will over action (Lafargue & Franck, 2009), whereas our data suggest that effort reduces implicit agency. Indeed, some authors have noted a dissociation between such measures, finding implicit agency measures and explicit judgments to be unrelated to one another (Dewey & Knoblich, 2014; Obhi & Hall; 2011). This again suggests that different sources of cues (e.g. sensorimotor feedback, temporal binding, retrospective judgements of agency) may contribute to the different levels of agency, and are themselves affected by different variables, accounting for dissociations between how responsible we can say we felt about an action compared with implicit measures. It could therefore be that manipulating effort in these paradigms could be a useful variable to explore the relationship between implicit and explicit measures of agency.

Conclusion

The present studies investigated the influence of physical and mental effort on temporal binding. It was found that the binding effect was reduced whilst under high effort in agentic conditions. It is concluded that effort generally and non-specifically affects implicit sense of agency, thought to be caused by depleted cognitive resources that would be otherwise dedicated to agency detection. When the effort is exerted by the same effector as that which is producing the environmental outcome, however, there is a more specific effect of effort whereby the individual's subjective experience of effort is taken into account. These results therefore further imply that a sense of agency is not necessarily generated in a uniform manner for any given action. Rather, the current state of the motor or cognitive system can disrupt a key mechanism that provides feedback about our actions in the environment.

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Figure Captions

Figure 1. Procedure for the Interval Reproduction task. In each condition the first event consisted of either a key press (Agency) or a tone (No Agency). After a randomised stimulus interval (500-1500ms) the outcome, a tone, was presented. Participants were prompted to respond by recreating the interval between the first and second events with the depression of the spacebar.

Figure 2. Effort manipulation set-up. Participants held the exercise band in their right hand for task-related physical effort (A), and in their left hand for task-unrelated physical effort (B).

Figure 3. Mean reproduction errors across factors Presence of Agency and Effort for each Experiment. Bars extending below the x-axis reflect an underestimation of the stimulus interval (temporal binding). Error bars represent the standard error of the mean for within-subject designs calculated using the procedure recommended by Loftus & Masson (1994). Asterisks indicate significant contrasts at $p<.05$.

Figure 4. The relationship between Effort Differential and Reproduction Error Differential. As Effort Differential increases Reproduction Error Differential increases. Cases with reproduction error differential values above zero are individuals who showed stronger effects of agency (vs. no agency) in low than high effort conditions.

Figure 5. Procedure for Experiment 3: Participants were presented with a string of letters, either two (Low effort) or eight (High effort), after which the Interval Reproduction task started. The first event consisted of either a spacebar press (Agency) or a tone (No Agency). After a randomised stimulus interval (500-1500ms) the outcome, a tone, was presented. Participants were prompted to make response intervals by recreating the interval between the first event and outcome with the depression of the spacebar, after which the probe letter appeared, prompting participants to respond as to whether it had appeared in the string at the encoding stage.

Figure 1.

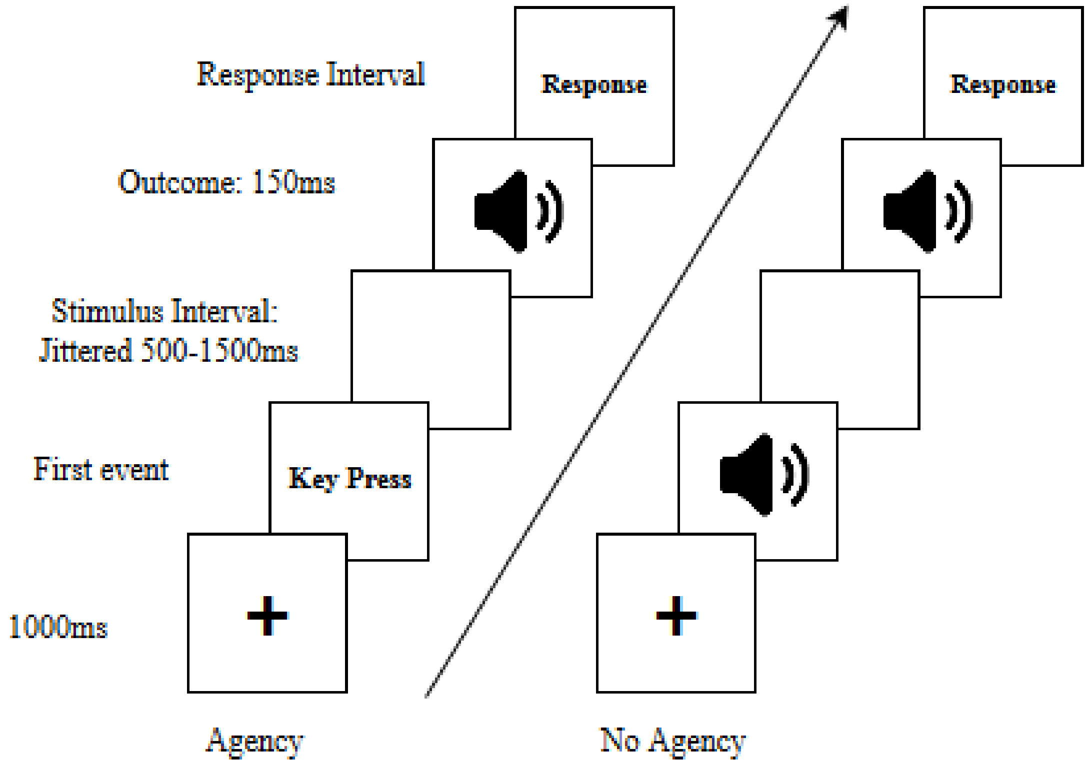


Figure 2.

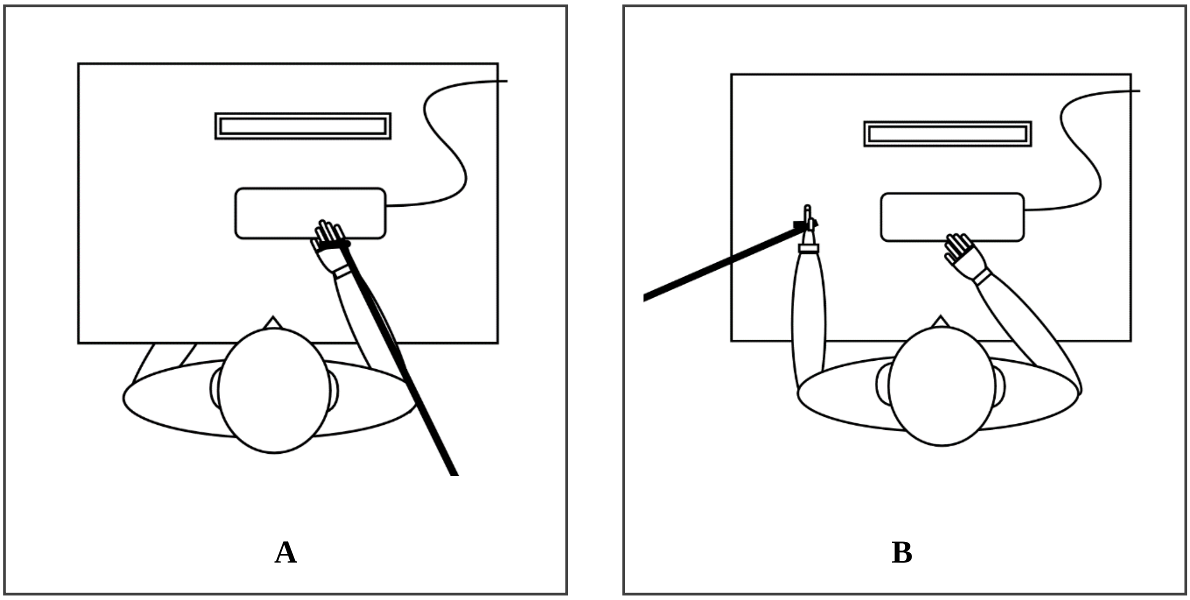
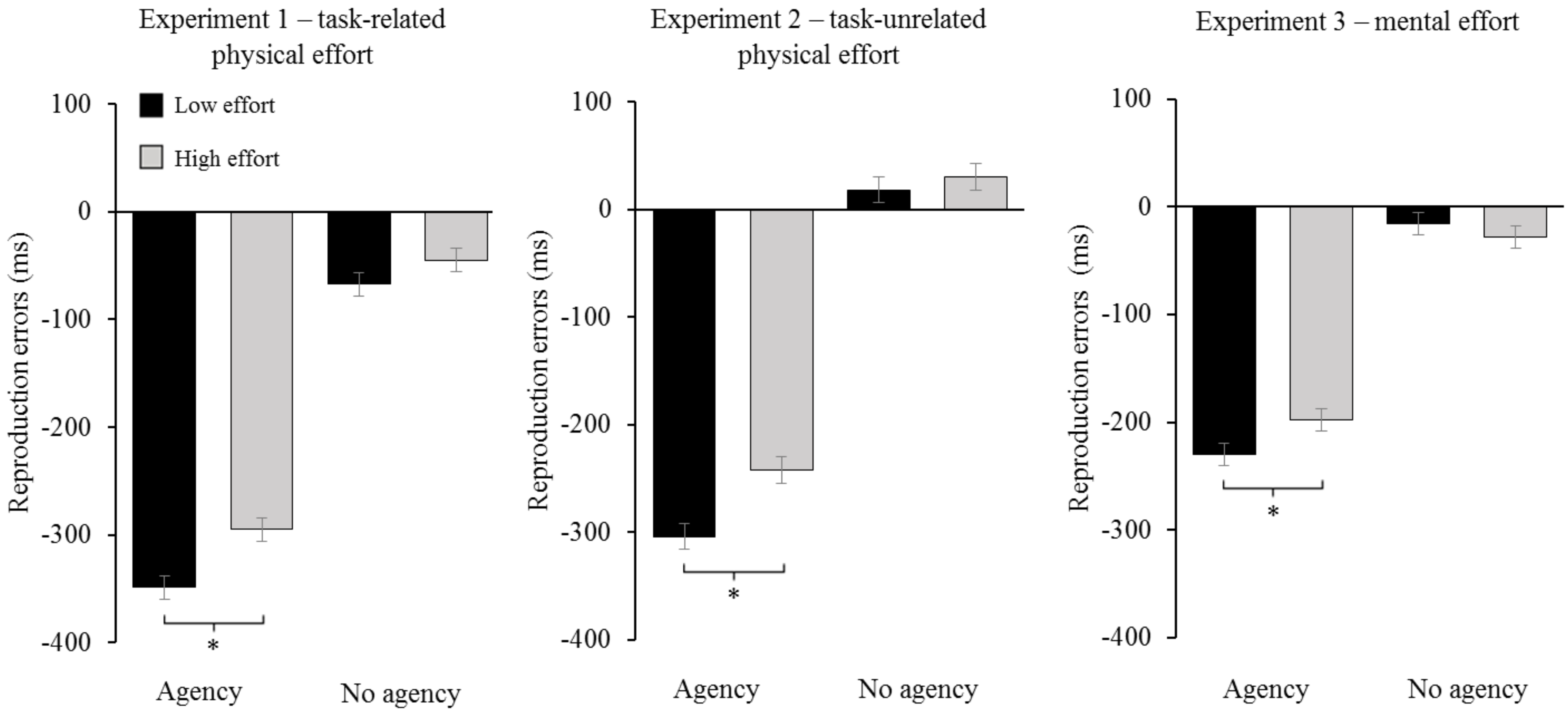
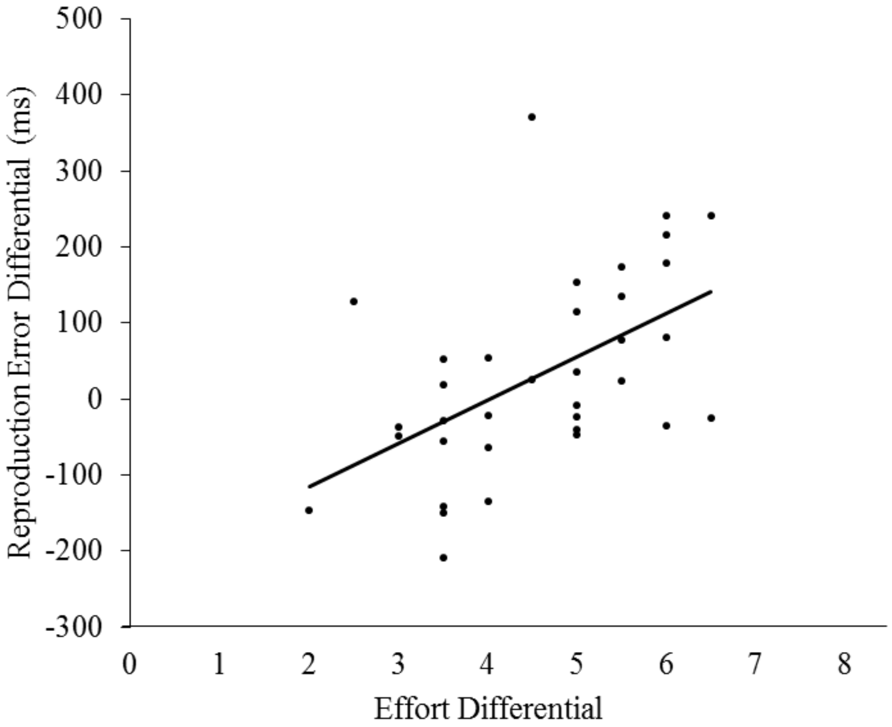


Figure 3.



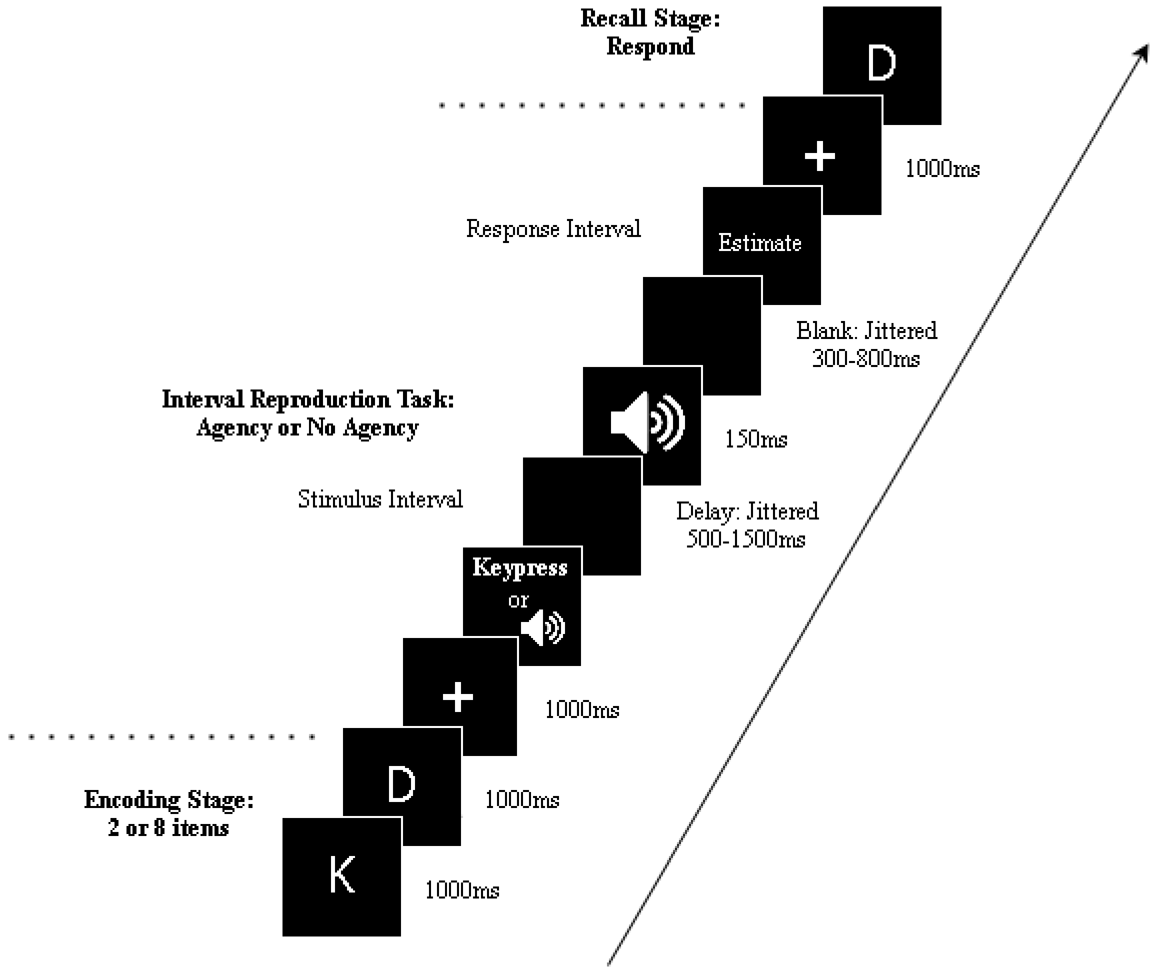
Experiment 1 – task-related physical effort
Low effort
High effort
Reproduction errors (ms)
100
0
-100
-200
-300
-400
*
Agency
No agency
Experiment 2 – task-unrelated physical effort
Reproduction errors (ms)
100
0
-100
-200
-300
-400
*
Agency
No agency
Experiment 3 – mental effort
Reproduction errors (ms)
100
0
-100
-200
-300
-400
*
Agency
No agency

Figure 4.



500
400
300
200
100
0
-100
-200
-300
Reproduction Error Differential (ms)
0
1
2
3
4
5
6
7
8
Effort Differential

Figure 5.


Recall Stage:
Respond
D
+
1000ms
Response Interval
Estimate
Blank: Jittered
300-800ms
Interval Reproduction Task:
Agency or No Agency
150ms
Stimulus Interval
Delay: Jittered
500-1500ms
Keypress
or
+
1000ms
Encoding Stage:
2 or 8 items
D
1000ms
K
1000ms

Appendix 2

SPQ-B (Raine & Benishay, 1995)

TABLE 1. The 22 Items Making Up the New SPQ-B Scale and Its Three Subscales

Questions should be administered in the order indicated by the number at the beginning of each question. Question numbers from the original SPQ scale are given in parentheses at the end of each item. The response format is Yes/No. All items endorsed Yes score 1 point.

Cognitive-Perceptual (Factor 1)

2. Have you ever had the sense that some person or force is around you, even though you cannot see anyone? (13)
4. Are you sometimes sure that other people can tell what you are thinking? (21)
5. Have you ever noticed a common event or object that seemed to be a special sign for you? (28)
9. Do you often pick up hidden threats or put-downs from what people say or do? (44)
10. When shopping do you get the feeling that other people are taking notice of you? (45)
12. Have you had experiences with astrology, seeing the future, UFOs, ESP, or a sixth sense? (47)
16. Do you ever suddenly feel distracted by distant sounds that you are not normally aware of? (61)
17. Do you often have to keep an eye out to stop people from taking advantage of you? (65)

Interpersonal (Factor 2)

1. People sometimes find me aloof and distant. (8)
7. I feel I have to be on my guard even with friends. (36)
11. I feel very uncomfortable in social situations involving unfamiliar people. (46)
14. Have you found that it is best not to let other people know too much about you? (52)
15. I tend to keep in the background on social occasions. (57)
18. Do you feel that you are unable to get "close" to people? (66)
21. I feel very uneasy talking to people I do not know well. (71)
22. I tend to keep my feelings to myself. (73)

Disorganized (Factor 3)

3. People sometimes comment on my unusual mannerisms and habits. (14)
6. Some people think that I am a very bizarre person. (32)
8. Some people find me a bit vague and elusive during a conversation. (42)
13. I sometimes use words in unusual ways. (50)
19. I am an odd, unusual person. (67)
20. I find it hard to communicate clearly what I want to say to people. (69)

Appendix 3

CAPs (Bell et al., 2006)

CA

Introduction

This questionnaire asks questions about sensations and perceptions you may have experienced. Some of the experiences are unusual, some of them are more everyday.

We realise circling answers may not always represent your experience as accurately as you might like. However, we would ask you to circle the answers that most closely match your experience and avoid missing any questions out.

We would appreciate it if you could be as honest as possible when giving your answers.

The only experiences we are not interested in are those that may have occurred whilst under the influence of drugs.

Instructions

Each item has a question on the left hand side. Please read the question and circle either YES or NO

- If you circle **NO** please move straight on to the next question.

- If you circle **YES** please rate the experience *in all of the three boxes* on the right hand side of the item by circling a number between 1 and 5.

These ask about how distressing you found the experience, how distracting you found it, and how often the experience occurs.

Example questions

You do not need to answer these questions, they are just examples to illustrate the instructions.

Do you ever notice that lights seem to flicker on and off for no reason ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

Do you ever feel that the sound on the TV or radio seems unusually quiet ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

1) Do you ever notice that sounds are much louder than they normally would be ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

2) Do you ever sense the presence of another being, despite being unable to see any evidence ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

3) Do you ever hear your own thoughts repeated or echoed ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

4) Do you ever see shapes, lights or colours even though there is nothing really there ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

5) Do you ever experience unusual burning sensations or other strange feelings in or on your body ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

6) Do you ever hear noises or sounds when there is nothing about to explain them ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

7) Do you ever hear your own thoughts spoken aloud in your head, so that someone near might be able to hear them ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

8) Do you ever detect smells which don’t seem to come from your surroundings ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

9) Do you ever have the sensation that your body, or a part of it, is changing or has changed shape ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

10) Do you ever have the sensation that your limbs might not be your own or might not be properly connected to your body?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

11) Do you ever hear voices commenting on what you are thinking or doing ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

12) Do you ever feel that someone is touching you, but when you look nobody is there ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

13) Do you ever hear voices saying words or sentences when there is no-one around that might account for it ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

14) Do you ever experience unexplained tastes in your mouth ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

15) Do you ever find that sensations happen all at once and flood you with information ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

16) Do you ever find that sounds are distorted in strange or unusual ways ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

17) Do you ever have difficulty distinguishing one sensation from another ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

18) Do you ever smell everyday odours and think that they are unusually strong ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

19) Do you ever find the appearance of things or people seems to change in a puzzling way, e.g. distorted shapes or sizes or colour ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

20) Do you ever find that your skin is more sensitive to touch, heat or cold than usual ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

21) Do you ever think that food or drink tastes much stronger than it normally would ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

22) Do you ever look in the mirror and think that your face seems different from usual ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

23) Do you ever have days where lights or colours seem brighter or more intense than usual ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

24) Do you ever have the feeling that of being uplifted, as if driving or rolling over a road while sitting quietly ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

25) Do you ever find that common smells sometimes seem unusually different ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

26) Do you ever think that everyday things look abnormal to you ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

27) Do you ever find that your experience of time changes dramatically ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

28) Have you ever heard two or more unexplained voices talking with each other ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

29) Do you ever notice smells or odours that people next to you seem unaware of ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

30) Do you ever notice that food or drink seems to have an unusual taste ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

31) Do you ever see things that other people cannot ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

32) Do you ever hear sounds or music that people near you don't hear ?

NO YES

If YES please rate on right hand side.

Not at all distressing				Very distressing
1	2	3	4	5
Not at all distracting				Completely intrusive
1	2	3	4	5
Happens hardly at all				Happens all the time
1	2	3	4	5

Appendix 4

SMSS (Mason et al., 2005)

Please Read the Instructions Before Continuing: This questionnaire contains questions that may relate to your thoughts, feelings, experiences and preferences. There are no right or wrong answers or trick questions so please be as honest as possible. For each question place a circle around either the YES or the NO. Do not spend too much time deliberating any question but put the answer closest to your own.

1.	Do you think that you could learn to read other's minds if you wanted to?	YES NO
2.	Are your thoughts sometimes so strong that you can almost hear them?	YES NO
3.	Are you much too independent to get involved with other people?	YES NO
4.	Do you ever feel that your speech is difficult to understand because the words are all mixed up and don't make sense?	YES NO
5.	When in the dark do you often see shapes and forms even though there is nothing there?	YES NO
6.	Do you find it difficult to keep interested in the same thing for a long time?	YES NO
7.	Can some people make you aware of them just by thinking about you?	YES NO
8.	Are you easily distracted when you read or talk to someone?	YES NO
9.	Do you often overindulge in alcohol or food?	YES NO
10	Do you like mixing with people?	YES NO
11	Does your sense of smell sometimes become unusually strong?	YES NO
12	Do you often feel the impulse to spend money which you know you can't afford?	YES NO
13	Do you prefer watching television to going out with people?	YES NO
14	Do you often feel like doing the opposite of what other people suggest even though you know they are right?	YES NO
15	Do you stop to think things over before doing anything?	YES NO
16	Do you dread going into a room by yourself where other people have already gathered and are talking?	YES NO
17	Is trying new foods something you have always enjoyed?	YES NO
18	Are there very few things that you have ever enjoyed doing?	YES NO
19	Do you often have difficulties in controlling your thoughts?	YES NO
20	Do you find the bright lights of a city exciting to look at?	YES NO
21	Do you consider yourself to be pretty much an average sort of person?	YES NO
22	Do you feel that your accidents are caused by mysterious forces?	YES NO
23	Would you like other people to be afraid of you?	YES NO
24	Have you ever felt the urge to injure yourself?	YES NO
25	Do you ever have a sense of vague danger or sudden dread for reasons that you do not understand?	YES NO
26	When you look in the mirror does your face sometimes seem quite different from usual?	YES NO

27	When in a crowded room, do you often have difficulty in following a conversation?	YES NO
28	Do you at times have an urge to do something harmful or shocking?	YES NO
29	Have you often felt uncomfortable when your friends touch you?	YES NO
30	Are you easily confused if too much happens at the same time?	YES NO
31	Have you sometimes sensed an evil presence around you, even though you could not see it?	YES NO
32	Do ideas and insights sometimes come to you so fast that you cannot express them all?	YES NO
33	Do you feel very close to your friends?	YES NO
34	Does a passing thought ever seem so real it frightens you?	YES NO
35	Are you a person whose mood goes up and down easily?	YES NO
36	Have you ever thought that you had special, almost magical powers?	YES NO
37	Has dancing or the idea of it always seemed dull to you?	YES NO
38	Do you love having your back massaged?	YES NO
39	Is it hard for you to make decisions?	YES NO
40	Are you usually in an average kind of mood, not too high and not too low?	YES NO
41	Do you ever have the urge to break or smash things?	YES NO
42	Are you easily distracted from work by daydreams?	YES NO
43	Do you frequently have difficulty in starting to do things?	YES NO

Score 1 for yes 0 for no

Grey numbered items are reversed

Appendix 5

DASS (Lovibond & Lovibond, 1995)

DASS

Name:

Date:

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

1	I found myself getting upset by quite trivial things	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I just couldn't seem to get going	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I had a feeling of shakiness (eg, legs going to give way)	0	1	2	3
8	I found it difficult to relax	0	1	2	3
9	I found myself in situations that made me so anxious I was most relieved when they ended	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting upset rather easily	0	1	2	3
12	I felt that I was using a lot of nervous energy	0	1	2	3
13	I felt sad and depressed	0	1	2	3
14	I found myself getting impatient when I was delayed in any way (eg, lifts, traffic lights, being kept waiting)	0	1	2	3
15	I had a feeling of faintness	0	1	2	3
16	I felt that I had lost interest in just about everything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I perspired noticeably (eg, hands sweaty) in the absence of high temperatures or physical exertion	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life wasn't worthwhile	0	1	2	3

Please turn the p

Reminder of rating scale:
0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

22	I found it hard to wind down	0	1	2	3
23	I had difficulty in swallowing	0	1	2	3
24	I couldn't seem to get any enjoyment out of the things I did	0	1	2	3
25	I was aware of the action of my heart in the absence of physical exertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	3
26	I felt down-hearted and blue	0	1	2	3
27	I found that I was very irritable	0	1	2	3
28	I felt I was close to panic	0	1	2	3
29	I found it hard to calm down after something upset me	0	1	2	3
30	I feared that I would be thrown by some trivial but unfamiliar task	0	1	2	3
31	I was unable to become enthusiastic about anything	0	1	2	3
32	I found it difficult to tolerate interruptions to what I was doing	0	1	2	3
33	I was in a state of nervous tension	0	1	2	3
34	I felt I was pretty worthless	0	1	2	3
35	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
36	I felt terrified	0	1	2	3
37	I could see nothing in the future to be hopeful about	0	1	2	3
38	I felt that life was meaningless	0	1	2	3
39	I found myself getting agitated	0	1	2	3
40	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
41	I experienced trembling (eg, in the hands)	0	1	2	3
42	I found it difficult to work up the initiative to do things	0	1	2	3

Appendix 6

SPIN (Connor et al., 2000)

Below are a list of statements. Please read each statement very carefully and rate how strongly these problems bother you. There are no right or wrong answers, or trick questions.

IN ORDER FOR THE SCALE TO BE VALID, YOU MUST ANSWER EVERY QUESTION.

	Not at all	A little bit	Somewhat	Very Much	Extremely
1. I am afraid of people in authority.	0	1	2	3	4
2. I am bothered by blushing in front of people.	0	1	2	3	4
3. Parties and social events scare me.	0	1	2	3	4
4. I avoid talking to people I don’t know.	0	1	2	3	4
5. Being criticized scares me a lot.	0	1	2	3	4
6. Fear of embarrassment causes me to avoid doing things or speaking to people.	0	1	2	3	4
7. Sweating in front of people causes me distress.	0	1	2	3	4
8. I avoid going to parties.	0	1	2	3	4
9. I avoid activities in which I am the centre of attention.	0	1	2	3	4
10. Talking to strangers scares me.	0	1	2	3	4
11. I avoid having to give speeches.	0	1	2	3	4
12. I would do anything to avoid being criticized.	0	1	2	3	4
13. Heart palpitations bother me when I am around people.	0	1	2	3	4
14. I am afraid of doing things when people might be watching.	0	1	2	3	4
15. Being embarrassed or looking stupid are my worst fears.	0	1	2	3	4
16. I avoid speaking to anyone in authority.	0	1	2	3	4
17. Trembling or shaking in front of others is distressing to me.	0	1	2	3	4

Appendix 7

EQ (Baron-Cohen & Cartwright, 2004)

Below is a list of statements. Please read each statement carefully and rate how strongly you agree or disagree with it by circling your answer. There are no right or wrong answers, or trick questions.

1.	I am good at predicting how someone will feel.	strongly agree	slightly agree	slightly disagree	strongly disagree
2.	I often find it difficult to judge if something is rude or polite.	strongly agree	slightly agree	slightly disagree	strongly disagree
3.	I can pick up quickly if someone says one thing but means another.	strongly agree	slightly agree	slightly disagree	strongly disagree
4.	If anyone asked me if I liked their haircut, I would reply truthfully, even if I didn't like it.	strongly agree	slightly agree	slightly disagree	strongly disagree
5.	I tend to get emotionally involved with a friend's problems.	strongly agree	slightly agree	slightly disagree	strongly disagree
6.	It is hard for me to see why some things upset people so much.	strongly agree	slightly agree	slightly disagree	strongly disagree
7.	If I say something that someone else is offended by, I think that that's their problem, not mine.	strongly agree	slightly agree	slightly disagree	strongly disagree
8.	People often tell me that I went too far in driving my point home in a discussion.	strongly agree	slightly agree	slightly disagree	strongly disagree
9.	I can easily work out what another person might want to talk about.	strongly agree	slightly agree	slightly disagree	strongly disagree
10.	In a conversation, I tend to focus on my own thoughts rather than on what my listener might be thinking.	strongly agree	slightly agree	slightly disagree	strongly disagree
11.	I am very blunt, which some people take to be rudeness, even though this is unintentional.	strongly agree	slightly agree	slightly disagree	strongly disagree
12.	I really enjoy caring for other people.	strongly agree	slightly agree	slightly disagree	strongly disagree
13.	I am good at predicting what someone will do.	strongly agree	slightly agree	slightly disagree	strongly disagree
14.	Friends usually talk to me about their problems as they say that I am very understanding.	strongly agree	slightly agree	slightly disagree	strongly disagree

15.	It doesn't bother me too much if I am late meeting a friend.	strongly agree	slightly agree	slightly disagree	strongly disagree
16.	Friendships and relationships are just too difficult, so I tend not to bother with them.	strongly agree	slightly agree	slightly disagree	strongly disagree
17.	Seeing people cry doesn't really upset me.	strongly agree	slightly agree	slightly disagree	strongly disagree
18.	I can usually appreciate the other person's viewpoint, even if I don't agree with it.	strongly agree	slightly agree	slightly disagree	strongly disagree
19.	Other people tell me I am good at understanding how they are feeling and what they are thinking.	strongly agree	slightly agree	slightly disagree	strongly disagree
20.	I find it hard to know what to do in a social situation.	strongly agree	slightly agree	slightly disagree	strongly disagree
21.	I am able to make decisions without being influenced by people's feelings.	strongly agree	slightly agree	slightly disagree	strongly disagree
22.	When I was a child, I enjoyed cutting up worms to see what would happen.	strongly agree	slightly agree	slightly disagree	strongly disagree
23.	I find it difficult to explain to others things that I understand easily, when they don't understand it first time.	strongly agree	slightly agree	slightly disagree	strongly disagree
24.	I can easily tell if someone else is interested or bored with what I am saying.	strongly agree	slightly agree	slightly disagree	strongly disagree
25.	Other people often say that I am insensitive, though I don't always see why.	strongly agree	slightly agree	slightly disagree	strongly disagree
26.	if I see a stranger in a group, I think that it is up to them to make an effort to join in.	strongly agree	slightly agree	slightly disagree	strongly disagree
27.	When I talk to people, I tend to talk about their experiences rather than my own.	strongly agree	slightly agree	slightly disagree	strongly disagree
28.	It upsets me to see an animal in pain.	strongly agree	slightly agree	slightly disagree	strongly disagree
29.	I can easily tell if someone else wants to enter a conversation.	strongly agree	slightly agree	slightly disagree	strongly disagree

30.	I can sense if I am intruding, even if the other person doesn't tell me.	strongly agree	slightly agree	slightly disagree	strongly disagree
31.	I don’t tend to find social situations confusing.	strongly agree	slightly agree	slightly disagree	strongly disagree
32.	I can tune into how someone else feels rapidly and intuitively.	strongly agree	slightly agree	slightly disagree	strongly disagree
33.	People sometimes tell me that I have gone too far with teasing.	strongly agree	slightly agree	slightly disagree	strongly disagree
34.	I find it easy to put myself in somebody else's shoes.	strongly agree	slightly agree	slightly disagree	strongly disagree
35.	I usually stay emotionally detached when watching a film.	strongly agree	slightly agree	slightly disagree	strongly disagree
36.	I don't consciously work out the rules of social situations.	strongly agree	slightly agree	slightly disagree	strongly disagree
37.	I am quick to spot when someone in a group is feeling awkward or uncomfortable.	strongly agree	slightly agree	slightly disagree	strongly disagree
38.	I get upset if I see people suffering on news programmes.	strongly agree	slightly agree	slightly disagree	strongly disagree
39.	I can't always see why someone should have felt offended by a remark.	strongly agree	slightly agree	slightly disagree	strongly disagree
40.	I can tell if someone is masking their true emotion.	strongly agree	slightly agree	slightly disagree	strongly disagree