Social Aspects of Agency:

The impact of social consequences and group dynamics on the sense of agency

PhD Thesis

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Declaration of authorship

I, Jack Moore, hereby declare that this thesis and the work presented in it is my own. Where I have consulted the work of other, this is always clearly stated.

Signed: _____, Date: 17th April 2021

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Abstract

The sense of agency refers to our sense of control over our actions and their subsequent effects. Recently, researchers have begun to consider the sense of agency when acting with others. This research has found that when interacting with another the *type* of agency we experience can change.

The current thesis aimed to understand how two aspects of our social world may affect the sense of agency. Our first two experimental chapters used an implicit measure (intentional binding) to assess how the social consequences of an action may affect the sense of agency. The first chapter found that, when acting with another, our agentic identity may shift, such that both participants consider themselves as part of an agentic whole. They also found that this can be manipulated by the perceived relationship we have with others. The second chapter indicated that, when acting alone, we implicitly feel more agency over self-interested, compared to pro-social, actions.

In our second two experimental sections we considered agency during co-ordinated joint actions. In these studies participants completed synchronous joint actions with one another. The first of these studies observed a negative correlation between the amount of agency we implicitly feel when acting alone, and how much we report when acting with others. Our final study assessed the relationship between our sense of agency and

group flow, observing group flow to be linked to *quantitative* but not *qualitative* changes in the sense of agency.

Finally, a discussion of the implications of these studies is given. This highlights the large effect that acting with others has on the weighting of sensory cues, as well as who should be considered liable for the outcomes of joint actions.

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Social Outcomes & Agency	June 2018
Poster Presentation, Future of Social Cognition (EPS)	Norwich, U.K.
Social Outcomes & Agency	June 2018
Poster Presentation, ASSC22	Krakow, Poland

1. Introduction

1.1. The social nature of action

Humans are social creatures. This ability, to co-ordinate actions with each other, and work together, was key in allowing homo-sapiens to succeed where other early hominids failed, and the foundation on which civilisation was created. By use of visual signals, such as hand gestures, or auditory signals, via speech, we can allow our actions to be instructed, and can direct the actions of others. For example, one may act to produce a thought in another; these words are written to direct your attention and spark your interest. In other situations, the *re*-action we are expecting may be emotional, such as when trying to build friendships, or physical, of which military manoeuvres are a clear example. Knowing the social impact of our actions has a large effect on how we feel about them. We may complete the exact same movements, such as signing one's name, but our experience will be vastly different depending on the consequences of it.

Moreover, who we act with will alter our experience. Co-ordinated group actions, such as dance or group rituals, have been documented throughout history, and across almost all cultures. Such joint actions appear critical for group identity, allowing us to feel connected to others, and making us feel a wider sense of control over our environment due to a shared identity. Moreover, when such egalitarian actions appear to be going well, people often

experience an implicit sense of joy and fulfilment in conducting them. This could be when musicians are ‘in the groove’ with each other, or a great partnership between teammates, or the whole team. As such, the epistemically private feeling of acting in such groups, often only occurring at the periphery of our conscious awareness, appears crucial for their effective use – to foster a shared identity, and effectively achieve a joint-goal.

This thesis aims to further our knowledge of these two social aspects of our actions: how the social consequences of them alter our experience, and how our experience of control changes when working with others.

1.2. The Sense of Agency

1.2.1. What is the sense of agency and why does it matter?

In normal life, we are generally aware of when we are in control of our actions, or when an external force is causing us to move. However, even without input from an external force, we are often unable to control our actions, whether this be the inability to prevent a yawn, to complete a skilled danced move, or type accurately on a keyboard. As such, a cognitive mechanism that can track the extent to which we consciously decide to act, and volitionally produce an action, is essential for us to be able to track control of our movements, and accurately ascribe responsibility for their effects.

The sense of agency refers to this experience: the experience of being in control of, and responsible for, our actions and their subsequent outcomes (Haggard, 2017; Moore, 2016). Its importance is well illustrated where we lose this sense of control, most notably in disorders such as schizophrenia (Hauser et al., 2011; Jeannerod, 2009; Moore & Fletcher, 2012). We can also feel a lack of agency over our actions as a result of our social environment, such as when our actions are instructed by others (Caspar et al., 2016; Pfister et al., 2014). Therefore, the sense of agency cannot be considered an exact cognitive representation of control over our motor actions, but more a marker for how much we *feel* in control whilst acting.

The experience of agency is also important for assigning criminal responsibility for our actions, where a person may have felt that they had no choice over their actions, even if they were made intentionally. The importance of assigning responsibility can be shown by considering the Nuremberg trials, in which those who reported they were only following the orders of others, and thus claimed not to feel responsible for their actions, were often not convicted of war crimes. In such situations, an individual may feel that, although they were the ones to complete the action, they are not responsible for their effects.

In sum, although often operating on the fringes of our conscious awareness, the sense of agency is an important cognitive mechanism, allowing us to accurately track our own impact on the world, and be aware of when we are not in control of our actions. This in turn feeds in to socially important notions of freedom and responsibility. Over the past two decades much research on the cognitive and neural underpinnings of the sense of agency has been produced, and it is this research that I now turn to.

1.2.2. Sense of agency and sense of ownership

Though vital, the sense of agency is a difficult concept to experimentally study, due both to its phenomenological thinness (Haggard, 2017) – often only occurring at the fringes of our conscious awareness – and its similarity to other, closely related concepts involved in monitoring our body and actions (Gallagher, 2000). In order to fully understand what is being

considered when discussing the sense of agency, it is important to distinguish it from other closely related cognitive mechanisms associated with movement and control of our body.

Normally, when we produce an action, we will experience both a sense that we are in control of our action (i.e. sense of agency), and that it is our body which is producing the action. **The sense of ownership** refers to the sense that it was *your* body that moved, irrespective of whether you are in control of it (Gallagher, 2000). When producing volitional actions, sense of agency and sense of ownership tend to coincide, and often occur only at the periphery of our conscious awareness. However, the two concepts are related to different neural processes involved in the planning and production of our actions. Whilst our sense of ownership is built into proprioception of our body and self-awareness of our movements, our sense of agency is related to processes involved in selecting, planning, and controlling our actions.

Synofzik, et al., (2008) offer a clear illustration of the difference between ownership and agency by describing the difference between alien and anarchic limb syndromes . The two syndromes are often confused or thought of as synonymous with each other. In fact, they are related to separate disorders.

Alien limb syndrome refers to a number of separate disorders in which one can feel that the limb is ‘alien’ to them (a disturbance of patients body representation. Jenkinson et al., (2018) describes two such disorders;

Somatoparaphrenia and asomatognosia. Asomatognosia refers to impaired visual recognition of the afflicted limb, typically occurring after right hemisphere stroke. Somatoparaphrenia is more complex, and involves the patient being unable to correctly attribute a limb to themselves, often inventing illogical explanations for why the limb is there, such as it belonging to their mother:

‘‘Examiner: Whose arm is this?

A.R. (patient): It’s not mine.

Examiner: Whose is it?

A.R.: It’s my mother’s.

Examiner: How on earth does it happen to be here?

A.R.: I don’t know. I found it in my bed.

Examiner: How long has it been there?

A.R.: Since the first day.”

(Bisiach, Rusconi, & Vallar, 1991)

Anarchic hand syndrome is a neurological condition in which goal directed actions occurs without the patients control (Jenkinson et al., 2015). Importantly, the patient still considers the limb as their own (an intact body representation) but are unable to control its movements

‘‘[The patient’s] left hand would tenaciously grope for and grasp any nearby object, pick and pull at her clothes, and even grasp her throat during sleep [...]. She slept with the arm tied to prevent nocturnal misbehaviour. She never denied that her left arm and hand belonged to her, although she did refer to her limb as though it were an autonomous entity”

(Banks et al., 1989, p. 456 as cited in Synofzik, Vosgerau, and Newen (2008).

Thus, as somatoparaphrenia, is characterised by patients experiencing their own limbs as alien to them, even without movement, it illustrates a disturbance in one’s sense of ownership. In contrast, anarchic hand syndrome is related specifically to a disturbance in the experience of controlling one’s movements (i.e. a disturbed sense of agency), whilst still claiming the arm to be one’s own (i.e. an intact sense of ownership).

Another distinction can also be made between a disturbance of ones self and one social agency experience. For example, patients with anosognosia for hemiparesis/plegia typically deny their paresis/-plegia and are convinced that their limbs function normally (Karnath & Baier, 2010). Such disorders cause a disturbed sense of agency and ownership due to their relation to their own self. In contrast, patients suffering from autism often have disturbed social abilities, such as being less able to understand the effect

their own attentional focus can have on others (Grynszpan, Bouteiller, et al., 2019), which may have a damaging effect one their sense of agency.

In sum, the current section has hopefully served to clarify what we mean by sense of agency, and to distinguish it from related aspects of self-experience, namely the sense of ownership. It should be noted that, our experience of agency may become more expansive, involving higher level perceptual and meta-representational processes, such as socio-cultural pressures that may influence how we experience our sensory events. In the next section, I will outline the development of these cognitive processes, and discuss the different conceptual levels at which our sense of agency can be considered.

1.2.3. Levels of agency – feelings and judgments

In order to experience a sense of agency a number of different cognitive abilities must already be present. First, we must be aware of our actions, and that through them, we are able to change our environment. This basic understanding of action-effect-coupling allows us to establish a self/environment distinction, including a representation of the environmental changes which result from our actions (for a more detailed discussion of action-effect-coupling see Vosgerau & Newen, 2007). Secondly, we must be able to use this understanding of action-effect-coupling in order to intentionally conduct a goal directed action. Without this secondary level of

comprehension (i.e. the ability to use our actions in order to accomplish a pre-planned goal), we will not experience a sense of agency over our actions and their effects; events will be experienced as happening to us, rather than as intentionally caused by us.

The development of awareness of our actions, from *registration* of action-effect-coupling, through to *prediction* of action-effects, can be seen in the study of neonatal infants. For example, 2-month old infants can modulate their sucking of a pacifier in order to improve the clarity of an audio stimulus presented to them (Rochat & Striano, 1999). Here the infant is able to register that the change in their behaviour results in a change in their environment. However, they cannot invert the causal reasoning; they are unable to *predict* the outcome that will result from their action, and thus form a sense of agency over it. This ability to predict does not occur until roughly 9-months of age (for a more detailed discussion of this two-step account of action control see Elsner & Hommel, 2001). Once we are a) able to attempt goal directed actions and b) predict action consequences, then a sense of agency begins to emerge.

In this first year numerous other self-representational processes emerge, and it is important to distinguish the sense of agency from these. Of pertinence for the current thesis, Gallagher (2000) made an important distinction between the minimal and narrative self. The **narrative self** is the self extended through time, as represented in the stories we tell of ourselves and our expectations of ourselves in the future. In contrast, the **minimal self**

can be considered the self un-extended through time (i.e. the immediate consciousness of oneself as the subject of experience), such as awareness that I am thinking about lunch, or that I am typing on the keyboard. According to Gallagher (2000), our sense of agency is encompassed within the concept of the minimal self, though this may depend on the level at which our actions are conceptualised.

Along with the difference in temporal continuity, a key difference between the narrative and minimal self is that, whilst we may misattribute our narrative self (e.g. mistakenly think I bought the last round at the bar, when in fact it was James), we cannot misattribute the minimal self (e.g. that I am drinking a beer). Thus, the minimal self is subject to the **immunity principle**; that we cannot be wrong that it is yourself who is thinking or acting. However, this may not hold when considering the sense of agency. It is only in rare cases, such as in mental disorders such as schizophrenia (Hauser et al., 2011; Jeannerod, 2009; Voss et al., 2010), where a misattribution of the minimal self can occur. According to Gallagher (2000), our sense of agency is encompassed within the concept of the minimal self, however this may depend on the level at which our actions are conceptualised.

The difference between the online experience of, and retrospective memory of, acting was discussed by Synofzik et al. (2008). They have suggested there are three fundamental levels to our sense of agency; feeling, thinking, and social interaction. At the lowest level of conceptualisation, we

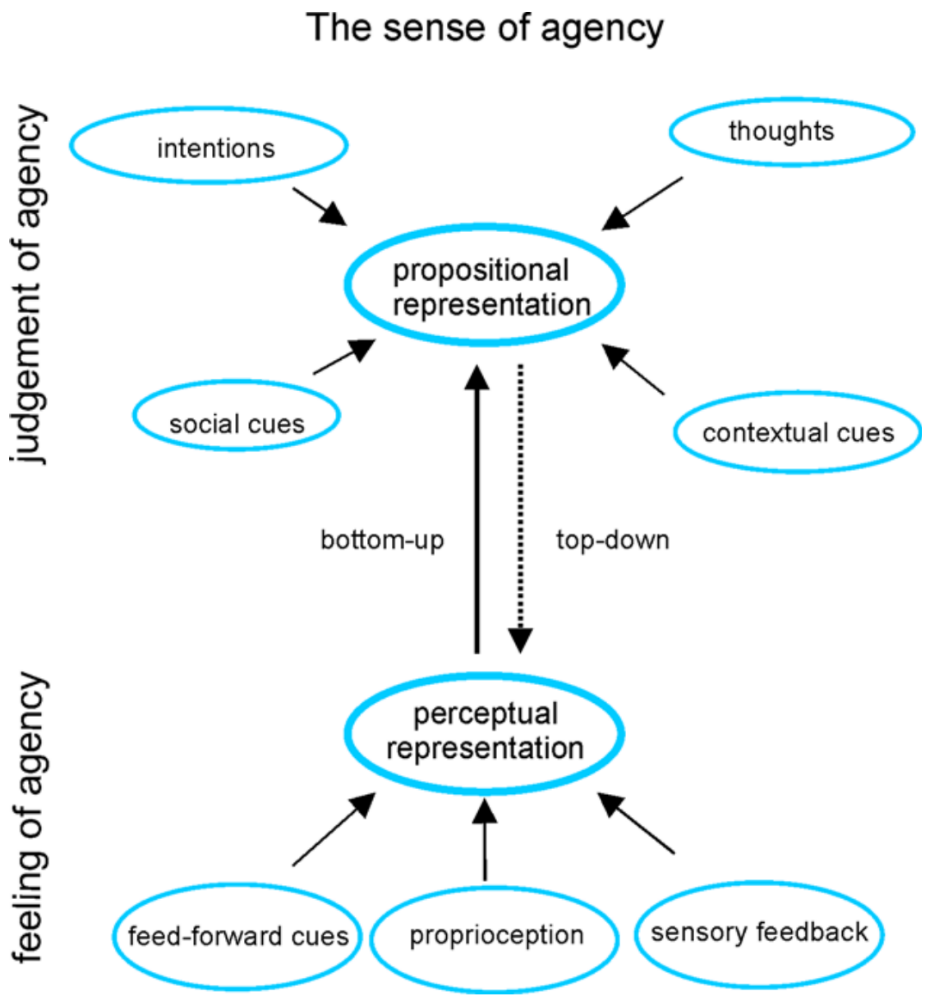
may have an implicit, in-the-moment, *feeling* of controlling our actions. The **Feeling of agency** refers to this pre-reflective, online experience, of controlling an action and its outcome. This occurs implicitly whilst producing an action, and can be assessed using implicit measures, which do not require consciously representing our actions. A feeling of agency emerges when there is congruency between our perceptual and motor cues, such as visual feedback and proprioception, which indicate an action to be self produced (see Figure 1). If there is a mismatch between these implicit cues then individuals may register the event as externally caused. As such, the feeling of agency only allows us to determine whether or not *I* was the cause of an action, though cannot tell us anything further.

In contrast, **Judgments of agency** refer to our conscious, reflective, attribution of agency. This occurs explicitly and uses both cues related to the feeling of agency, as well as external environmental cues, such as the presence of another agent, to determine authorship of an action and its subsequent effects (see Figure 1). The implicit feeling of producing an action is further processed in relation to our prior beliefs about the action and the possible influence of external agents. This ad hoc rationalisation may lead to a re-appraisal of the sense of agency. At this level, we can determine both if an action was self-made or not self-made, and who else may have produced the action, if not us. The sense of agency at this level of conceptualisation is assessed with explicit measures.

The difference between the two concepts can be further considered in relation to Gallagher's (2002) distinction between our minimal and narrative

Figure 1

Illustration of two step account of agency. Re-printed from Synofzik et al.(2008)



selves. Our feeling of agency occurs in-the-moment, thus can be considered an aspect of the minimal self as it is un-extended through time. Moreover, the

feeling of agency cannot be misattributed to another, thus is subject to the immunity principle. In contrast, judgments of agency are extended through time as a judgment occurs *after* the event. Plus, we may be able to misattribute a judgement of agency. This suggests that, depending on how we conceptualise our actions, our sense of agency may be related to the minimal self, narrative self, or both.

Finally, the highest level of Synofzik et al. (2008) model, relates to who is morally responsible for an action or outcome. Often an individual may intentionally produce an action which they do not wish. Such actions may be common in the military, where a private may be instructed to produce an action which will harm others, knowing that, as long as they are 'following orders', they are not morally responsible for its effects. Also, someone may not be aware of the normative effects of such an action and of the normative consequences of an action on others; if we are unaware that pushing a button will cause pain to another, can we be considered morally responsible for hurting them? Such experiences require an understanding of socio-cultural norms, and a representation of the mind of others. Though attributions of moral responsibility are clearly important, the current thesis will focus on the two lower levels, which consider the phenomenology, rather than the ethical implications, associated with our actions.

In sum, agency is not a uni-dimensional concept. At some points we may be so focused on our actions that we have an intense feeling of agency.

At others, we may be more aware of our environment and the possible influence of other agents, resulting in more judgments of agency. Thus, depending on the environment and the action, our experience of agency will change (Bayne & Pacherie, 2007), with a wide range of sensory cues that could influence the sense of agency. As such, a number of different models have been suggested. In the next section I discuss the three main theoretical models of the sense of agency.

1.2.4. Models of the sense of agency

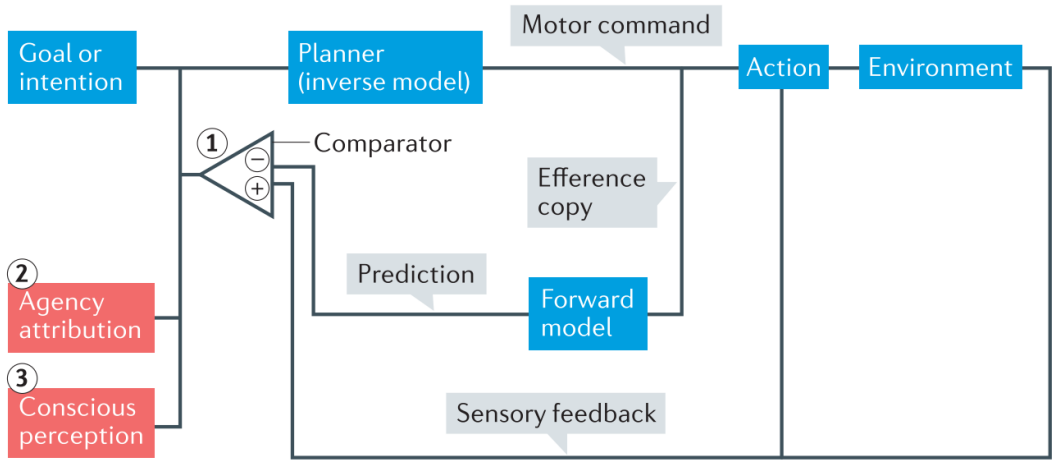
Broadly, there are two schools of thought on the processes underlying the sense of agency; those that focus on the role of low-level sensorimotor processes, and those that also consider the role of non-motoric processes (i.e. situational factors). Both approaches are considered important in forming our sense of agency and, more recently, have been combined into a single model which integrates both interoceptive and exteroceptive signals. Below, an overview of the two different approaches, and the evidence supporting them, shall be given. Then, theories illustrating how they can be integrated shall be presented and explained.

Sensorimotor processes have long been considered important for generating our sense of agency. According to the comparator model, the sense of agency is intimately tied to the predictions made by our motor system (Blakemore, Wolpert, & Frith 2002). The model suggests that, once the

decision to act has been made, a motor command of the required actions is issued, and a copy of this command is sent to a *forward model*, which creates a prediction of the future state of the motor system, as well as the likely sensory consequences of the movement. In order to compute the sense of agency, the system compares the predicted sensory consequences with the actual sensory consequences (see Figure 2). For example, if the model of our action is to lift an empty kettle, and the kettle is in fact full of water, there will be a mismatch between our forward model and the experience itself, leading to a reduced sense of agency over the event.

Figure 2

Illustration of the comparator model. Re-printed from Haggard (2017).



Note. The comparator model may be used in three ways: (1) To adjust our current motor command; (2) for attribution of agency to our actions and environmental events; (3) attenuation our sensory response to self-produced events.

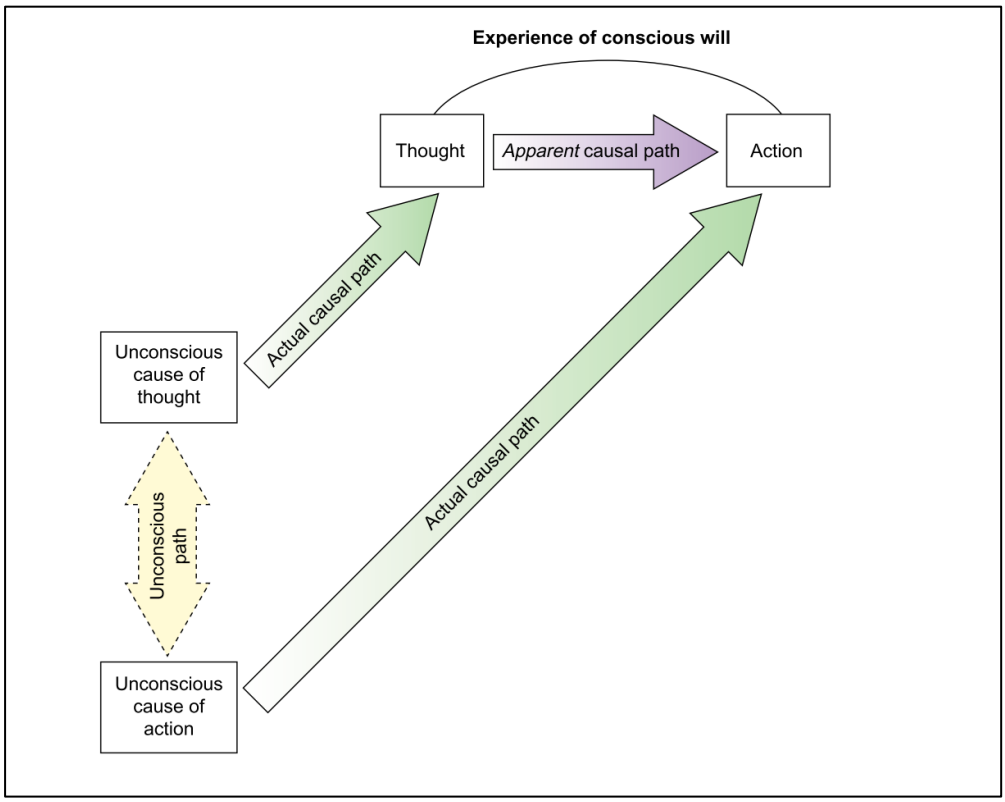
A real-world illustration of how the model has helped us to understand our actions is its ability to explain why we cannot tickle ourselves. The model suggests that if we are able to accurately predict sensory information, such as when tickling ourselves, then the information will not require further processing. Unpredictable sensory events, such as the unpredictable movements of another's hand, require a heightened level of processing and conscious awareness, leading to the sensation of being tickled; due to the unpredictability of the movements of the tickler there is increased sensorimotor feedback of the sensation, resulting in the sensation of being tickled. Moreover, researchers have shown that when there is a disparity between the prediction and production of ones own self-touch actions, individuals can experience the sensation of tickling oneself (Blakemore et al., 1999). Similarly, schizophrenic patients, who are unable to accurately distinguish between self and other, can also tickle themselves (Blakemore et al., 2000). This example thus illustrates how our internal predictions regarding an action play a key role in the sense of agency.

Nonetheless, whilst the ability to accurately predict our movements and their effects is clearly important, exteroceptive changes in the sensory environment can also have a large effect. In contrast to motor command driven models, some have suggested that processes related to external cues can also play a role. Wegner's (2002) **theory of apparent mental causation** suggests that much of the processing involved in volitionally producing an

action occurs *before* our conscious awareness of the decision to act (See Figure 3). Moreover, it argues that the extent to which we experience a sense of agency over our actions will be much more dependent on external, environmental factors, rather than internal models of our motor commands. The theory suggests that a) when a thought to act occurs just prior to the production of an action, b) with that action being consistent with the prior thought, and c) is not accompanied by other possible causal explanations, then we will experience a strong sense of agency over the action and its subsequent

Figure 3

Illustration of apparent and real causal paths. Re-printed from Wegner (2013).



outcome. Therefore, the theory considers the situation in which an action is produced to be of much greater importance than accurate internal models of our motor commands. Support for this theory can be found in many of the spiritualist activities popular in the late nineteenth century, such as table turning (Wegner, 2003), where people deny agency over an act due to a belief in another cause. It can also be seen in the illusory sense of control often reported when believing you are the cause of an event, such as by use of a voodoo doll (Pronin et al., 2006).

These two approaches illustrate how both internal models of our actions, and external environmental conditions, can effect the sense of agency. As such, a model which considers both interoceptive and exteroceptive signals has been proposed. **The cue integration model**, which uses a Bayesian statistical approach to incorporate the weighted reliability of multiple sensory inputs, can account for changes in the sense of agency (Moore & Fletcher, 2012). The approach has been shown to correspond with computational models of sensory integration, which suggest that visual and haptic sensory inputs may be combined in the style of a 'maximum-likelihood integrator' (Ernst & Banks, 2002). This would integrate multiple sensory inputs, with their influence dependant on the signal-to-noise ratio of the sensory input in order to minimise the overall variance in any perceptual decision.

This, cue integration model, is supported by experimental research illustrating that when the reliability of motor signals is reduced, external cues will have a greater influence on the sense of agency (Moore et al., 2009; Moore & Haggard, 2008). One of the first studies to indicate that the reliability of sensory signals can affect their significance in forming the sense of agency was conducted by Moore and Haggard (2008). They measured intentional binding – the perceived temporal compression of the interval when one makes a voluntary action (see section 1.2.6 for a full discussion of intentional binding; Haggard, Clark, & Kalogeras, 2002; Tsakiris & Haggard, 2003). The experiment involved two conditions, in one a self-produced action had a high (75%) probability of producing an outcome (tone), in another the probability of outcome was low (50%). The researchers observed that when one's actions had a high probability of producing an outcome, intentional binding of the action – the shift of the perceived time of the action towards the outcome – would occur even on trials without an outcome. However, on trials in which the probability of producing the outcome was low, intentional binding would only occur on trials in which the action produced an outcome. This illustrates that when the reliability of an outcome signal is high, the sense of agency can occur, even in their absence. Whereas, when the reliability of those sensory signals is low, the sense of agency may only be inferred when they occur. The study therefore illustrates how, depending on their reliability, the importance of different cues changes.

In sum, current models of the sense of agency have illustrated the importance of both sensorimotor and exteroceptive events, with the cue integration model allowing for the unique contribution of each to be understood. Depending on the action, and the environment it is completed in, cues will have a different effect on our sense of agency, leading to a different weighting in the cue integration model. By designing experiments in which the weighting of different sensory cues may be adapted, and computing them within the cue integration model, we are able to test the importance of individual sensory signals on the sense of agency. It is the methods used to measure the sense of agency that I shall now turn to.

1.2.5. Measuring the sense of agency

The methods used to assess the sense of agency can be categorised into two groups; implicit and explicit. Explicit measures require participants to report on their experience of agency when performing an action. This can include asking participants to make simple binary – yes/no - judgments regarding whether they are observing their own, or another's, actions (e.g. Franck et al., 2001), or making more refined estimates of the degree to which they felt responsible for the outcomes of their actions (e.g. Beyer et al., 2016; Wegner et al., 2004). More recently, questionnaires have been developed as an alternative way of probing our explicit experience of agency. For example, Polito et al. (2013) developed the Sense of Agency Rating Scale (SOARS), which allows for differences in the sense of agency to be measured, and for

the differences between people's agentic experience, such as those due to their hypnotisability, to be attributed to specific factors.

Explicit measures have certain advantages. Firstly, explicit measures allow you to directly assess a person's conscious experience of their actions, in this way it could be argued that the measure is closer to the subjective experience. Also, using explicit measures, researchers can ask about specific aspects of an action-outcome event. For example you may ask whether a participant felt any agency over an action (e.g. Wegner, Sparrow, & Winerman, 2004), or outcome (e.g. Beyer et al., 2016), or the extent to which they felt they were acting in partnership with another (e.g. Bolt & Loehr, 2017). Thus, explicit measures have numerous advantages, allowing us to reliably understand one's experience of an event.

Nonetheless, as with all subjective reports, they are not without issue. For example, even though explicit reports may not affect our online experience of agency, the measure is reliant on accurate retrospective inference. Also, if the participant is unclear as to what is being asked, their response may be incorrect. Experimenters may ask participants whether they think their action caused a subsequent event (Ebert & Wegner, 2010), or about their expectation of an outcome occurring on the next trial (Moore et al., 2012). Clearly both these examples relate to different experiences and, though both relate to our sense of agency over an event, the cognitive processes involved in reporting our sense of agency over them may be different. Moreover, when our actions

are considered in a social context, judgements of agency can become harder, and more complex, as participants may be affected by how they are viewed by others. Similarly, when acting with others, though a question may ask participants about their individual sense of agency over the event, a participant's answer could be more representative of group level concepts of agency (van der Wel, Sebanz, & Knoblich, 2012). As a result of these issues, it can be hard to be certain that responses truly represent the aspect of agency researchers are purporting to measure.

Implicit measures represent an alternative approach to the measurement of the sense of agency, and offer, to some extent, a solution to certain issues associated with explicit measures. The two most common implicit measures are intentional binding and sensory attenuation. **Intentional binding** refers to the perceived compression of time between a volitional action and its outcome (for a full discussion see section 1.2.5.; Haggard et al., 2002; Moore & Obhi, 2012). **Sensory attenuation** refers to the attenuation of sensory processing of events triggered by human actions. It can be measured behaviourally, for example by asking participants to report the strength of a sensory stimulus (e.g. Blakemore et al., 1999), or by looking at neural correlates of sensory processing, for example by comparing the N100 in self vs. non-self produced conditions (e.g. Hughes, Desantis, & Waszak, 2013; Wolpert, Ghahramani, & Jordan, 1995).

Using implicit measures has many advantages. Firstly, implicit measures allow participants' agentic experiences to be measured without requiring them to consciously conceptualise an event. This allows for lower level cognitive processes associated with the sense of agency to be assessed. Second, they are less susceptible to demand effects that can influence explicit reports – because the participant is not being directly asked about their agentic experience the measure is unlikely to be contaminated in this way.

Despite their advantages, there are certain issues with implicit measures. For instance, binding and sensory attenuation can occur for observed actions, which may suggest that they are related to broader agentic attributions, rather than reflecting *self* agency specifically (Poonian & Cunnington, 2013; Poonian, McFadyen, Ogden, & Cunnington, 2015). Whilst not requiring participants to consciously recollect the amount of control they felt an event, the method is still retrospective in nature; requiring participants to recall their experience of the position of a clock hand (Libet clock method), or perception of the time interval (interval estimation methods; see1.2.6). Also, unlike explicit measures, they require both an action *and* an outcome, and thus cannot assess agency over just an action – this commits the researcher to a certain aspect (or even conceptualisation) of the agentic experience. Finally, implicit measures are only assessing the sense of agency by proxy, it is presumed that these measures are an accurate indicator of the sense of agency, though they may also be related to, and be affected by, other cognitive

processes. Thus, whilst useful, it should be understood that implicit measures are dependent on how strongly they can be associated with the sense of agency.

The strength of this association between implicit measures and the explicit sense of agency has been questioned. What has been observed is that the correlation between implicit and explicit measures depends on the method being used. Whilst sensory attenuation has not been shown to correlate with other methods used to assess the sense of agency (Dewey & Knoblich, 2014; Pyasik et al., 2018), intentional binding and self-reports correlate in some (Ebert & Wegner, 2010; Imaizumi & Tanno, 2019; Pyasik et al., 2018), but not all, studies (Dewey & Knoblich, 2014; Lafleur et al., 2020; Moore et al., 2012; Saito et al., 2015).

Due to the different conceptual levels at which the measures assess the sense of agency, and the ambiguity regarding their correlation, it has been suggested that implicit and explicit measures may relate to different, but interdependent aspects of agency (Dewey & Knoblich, 2014; Ebert & Wegner, 2010; Moore et al., 2012). More specifically, the two methods may represent the different conceptual levels of the sense of agency outlined by Synofzik et al., (2008). Implicit measures would indicate our low level, non-conscious, *feeling* of agency, whilst explicit reports reflect our high level, conscious, *judgements* of agency. These two conceptual levels of agency are additive, with inputs from the lower level feeling, as well as other sensory

cues, feeding into our higher level judgments. As such, a correlation between the methods should be observed when they are both equally reliant on the same sensory cues.

In sum, it appears that each measure may tap into different processes involved in our sense of agency. Implicit measures may relate more to the online *feeling* of volitionally producing an action, whilst explicit measures are related to our retrospective *judgements* of who was in control. As mentioned previously, our feeling of agency occurs online, and without conscious recollection of our action. Such an experience, due to its innate obscurity to our consciousness, would be difficult to measure using explicit measures; how are we supposed to accurately report on something we are only vaguely aware of? In contrast, explicit measures are perfectly suited for making judgements of agency. At this conceptual level, we are fully conscious of our actions, and are more dependent on exteroceptive cues. Thus, when thinking about the sense of agency, we must be aware of the different levels at which it can be conceptualised, and how manipulating different cues may affect the specific measure that is being used. Stated clearly, implicit and explicit measure of agency may relate to lower and higher levels of agency respectively. It is also important to distinguish between retrospective which include explicit self-report measures and intentional binding and online measures – studies which have used neurophysiological measures recorded at time of event as indicators of the

sense of agency. Numerous studies in this thesis used the intentional binding paradigm to assess the sense of agency. As such, a more in-depth analysis of this method shall now be given.

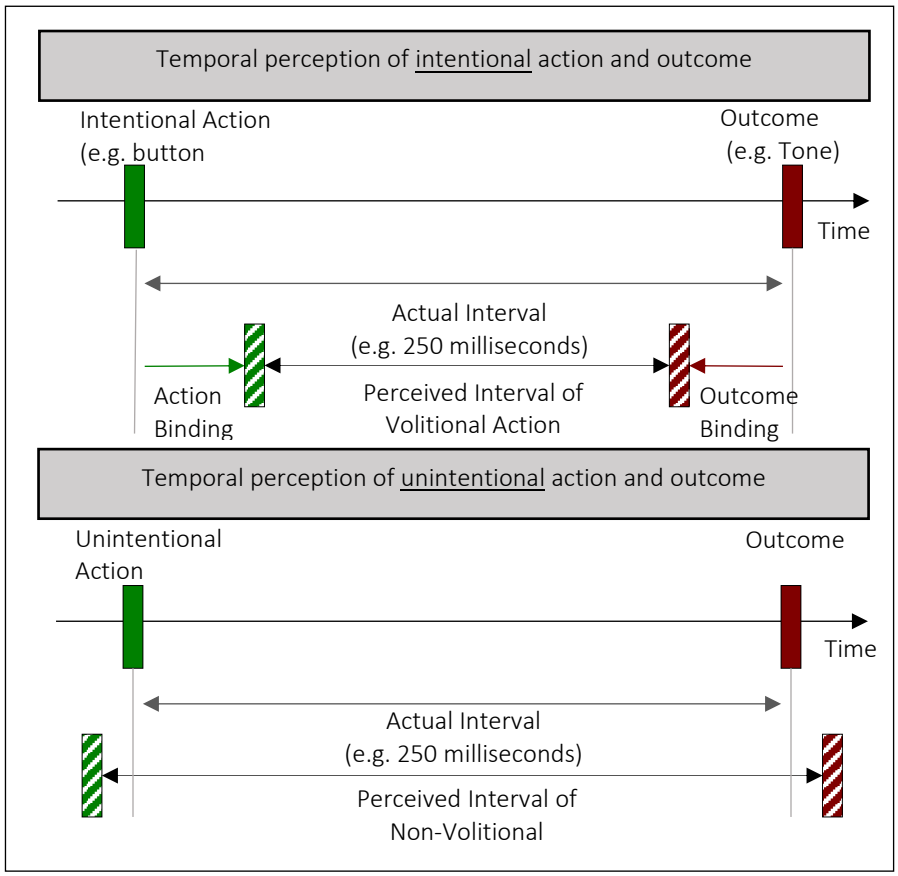
1.2.6. The intentional binding paradigm

The first and second experimental section of this thesis presents a series of studies using the intentional binding paradigm. As such, a more in-depth review of the method shall be given. The original study (Haggard et al., 2002) assessed how causality and volition affect temporal perception. Participants were required to fixate on a Libet clock (Libet et al., 1983). This consists of a clock face marked at conventional intervals (5, 10, 15, etc.) and a single hand which makes a full rotation every 2,560ms. Participants were asked to estimate the position of the clock hand when one of several sensory events occurred. The experimental design involved comparing the perceived time of an action or tone in four key conditions. In baseline conditions participants either depressed a key or heard a tone (occurring without action). Afterwards they were required to indicate the perceived time of the clock hand. In operant conditions participants made a key press, which was followed by a tone 250ms later. Then, in separate blocks, participants were required to report the perceived time of the clock hand when either the key press, or tone, occurred. The authors found that, in the operant condition, the perceived time of action was shifted towards the tone, and the perceived time

of the tone was shifted towards the action, such that the events had become temporally *bound* together. Critically, using the same set of conditions, but with an involuntary movement, caused by transcranial magnetic stimulation (TMS), the exact opposite effect was observed; the two events became temporally *repelled* from each other.(see Figure 4). The design therefore

Figure 4

Illustration of intentional binding effect.



Note. For intentional actions the perceived time of the action and outcome are perceived as temporally closer to each other. For unintentional act the two are perceived as further away.

shows how *intentional* actions and their outcomes are perceived as temporally *bound* together, leading to the term intentional binding. Since the original study, the effect has been widely replicated and is now commonly used to measure the sense of agency.

Since the original study, the paradigm has been altered in numerous ways. For example, researchers have observed the same binding effect with action-tone intervals of up to 4 seconds (Buehner & Humphreys, 2009). Moreover, it can be easily altered to assess visual rather than auditory outcomes (e.g. Stephenson, Edwards, Howard, & Bayliss, 2018). One common adaptation is that, rather than having the time of the action and tone recorded separately using the Libet clock, participants are asked to retrospectively estimate the interval between an action and outcome (Engbert et al., 2007). The **interval estimation** design involves two experimental blocks, in one participants make a volitional key-press, in another the key-press is made non-volitionally – their hand may be forced onto a key by the experimenter or a robotic mechanism. This will then produce a tone after one of several fixed delays. Once the tone has occurred, participants are asked to estimate the action-tone interval in milliseconds. As the perceived time of action and outcome do not need to be recorded separately, the interval estimation design greatly reduces the number of trials needed to assess intentional binding. Though the method does sacrifice a level of precision regarding the participants' perception of each sensory event, it is better suited

for more complex experimental designs, where the number of baseline and operant blocks can exponentially rise. Using this more compact design, researchers have illustrated that we feel greater agency when we have more action options (Barlas & Obhi, 2013), and that it may be reduced when interacting with others (e.g. Pfister et al., 2014).

Although intentional binding is widely used and has been widely replicated, there are some criticisms of the paradigm. Some researchers have argued that intentional binding is more indicative of broader concepts of causal attribution, rather than specifically reflecting intentional actions (Buehner & Humphreys, 2009; Suzuki et al., 2019). In one such study Buehner and Humphreys (2009) manipulated the extent to which a tone was contingent on a participants action, or a prior tone. In their study participants completed one of two training phases. In the *non-causal* training phase participants learnt that a tone (t1) indicated the presentation of a second tone (t2) after 500, 900 or 1300ms. In the *causal* training phase participants learnt that their action would *cause* t2 to occur after the same interval. Both groups then completed a second training phase in which they heard a succession of tones – t1-t2 repeated – and were required to synchronize a key press with t1. For the causal group the temporal interval to t2 was contingent on their action, whilst for the non-causal group the time of t2 was contingent on the time of t1. In a final test phase both groups had to press a key at the time of both tones. When measuring the time of these key presses, they observed that the

interval between t1 and t2 key presses was shorter (i.e. increased intentional binding) in the causally, compared to non-causally, primed group. They argued this result indicates that intentional binding is more indicative of causality, rather than intentionality. However, whilst their findings indicate the importance of causality to the intentional binding effect, their study fails to tell us about the importance of intentionality as it was not manipulated.

In another study (Suzuki et al., 2019) participants wore a virtual reality (VR) headset and either pressed, or observed a button being pressed, that caused a tone. In one condition they pressed a virtual button which resulted in a tone, in another they observed a recording of their own virtual hand pressing the button followed by a tone, in a final condition the button depresses on its own. The researchers observed that interval estimates in the no-hand condition were significantly longer than in the observed hand and self-produced action conditions. The researchers argue that, as in the TMS and sham-TMS conditions of the original intentional binding study (Haggard et al., 2002), in the no-hand condition there is no causal link between the action and tone, and this explains the longer interval estimates. However, in this final condition, there is also no agent to act. As an agent is required in order for an intentional action to be made, it is unsurprising that estimates would be significantly longer in this condition. In fact, such a finding would fit with the argument that intentional binding is indicative of an *agent* acting *intentionally.*

A final criticism is that intentional binding can also be reported for observed actions (Engbert et al., 2007; Obhi & Hall, 2011a; Pfister et al., 2014; Poonian & Cunnington, 2013; Sahaï et al., 2019). Though it is true that intentional binding can occur for observed actions, when comparing a self produced action in isolation, there is a reliable difference between volitional and non-volitional conditions. The paradigm may thus be used to study self-agency when studying an individual in isolation, and also study how we perceive others' actions when observing, or acting, in groups. Also, the effect has not been reliably observed for robots or computers (Caspar et al., 2015; Obhi & Hall, 2011b; Sahaï et al., 2019). As such, it appears there is something unique about observing a human agent complete an action, which results in the intentional binding effect. In fact, the paradigm's reliance on human agency for the effect to occur, and that it can be reported for observed actions, may make it the perfect tool to understand how our sense of agency is affected by our social world, allowing us to assess how we experience agency over both our own, and others', actions. Thus, whilst it has yet to be extensively researched, the paradigm may allow us to look at our experience of agency in the context of social relationships. This is something I address in the first experimental section of this thesis.

1.3. Sense of agency in a social setting

1.3.1. Actions in a social setting: *quantitative* effects on self-agency

Whilst much research has been conducted on one's sense of agency over individual actions, researchers have only recently started to look at how it functions when interacting with others. Rarely do our action's take place in a social vacuum; often, our actions are completed in order to cause an effect on others, or we co-ordinate our actions with others. In this section I consider how the social setting of an action influences the *strength* of one's sense of agency over self-produced actions. In this way, I will be looking at *quantitative* changes in the sense of agency arising from changes in the social context (the next section will look at *qualitative* changes in the sense of agency arising from changes in the social context, that is changes in the *kind* of sense of agency that is experienced).

One quantitative effect is the reduction in sense of agency which arises when there are others who could act in our stead. Such diffusion of responsibility effects have long been shown to impact our propensity to act (Mynatt & Sherman, 1975). For example, research has shown that individuals are less likely to respond to mass, compared to individualised, emails (Barron & Yechiam, 2002). More recently, diffusion of responsibility has been shown to affect the amount of agency we experience; when we think another could have acted instead of us, we are likely to feel a reduced sense of agency over our actions. Beyer et al. (2016) asked participants to complete an action

which produced a more, or less, negative outcome under two conditions. In one condition they believed they were the only one who could have acted, in another they believed another could have acted instead of them. When they believed another agent could have acted, participants reported feeling less agency over the outcome of their actions. Furthermore, neuroimaging research has illustrated that the neural processes underlying the effect of another's presence, and our experience of the sense of agency, are related to physiologically separate, but interacting brain regions, the latter being modulated by social context but not sensitive to sense of agency (Beyer et al., 2018). Therefore, it is clear that knowing who else is present, and whether they could have acted, can have a mediating effect on the sense of agency.

When those present are also instructing our actions, our sense of agency can also, unsurprisingly, be diminished. Whilst the effects of authority have long been known (e.g. Milgram, 1963), only recently have we begun to understand its effect on our sense of agency. One such study (Caspar et al., 2016) assessed the effect of coercion on the sense of agency. The paradigm involved participants producing an action that would cause harm to another. These actions were either coerced by a confederate, or freely chosen. As predicted, there was a reduction in the sense of agency when the participants actions were coerced. This suggests that, when our actions are forced by another, we may not *feel* any agency over them, and not retrospectively *judge*

ourselves responsible for them. Thus, even when our actions are intentionally made, being forced to act may result in us taking no responsibility for them.

In contrast, an increase in one's own sense of agency can arise in situations where one is instructing others to act. For example, Pfister et al. (2014) conducted an intentional binding study in which participants were assigned to *leader* and *follower* roles. The leader's action would cause a tone which acted as a trigger, indicating to the follower that they should now act. Leaders were shown to have increased intentional binding for both the interval between their actions and outcomes, as well as the subsequent social consequences of their actions; i.e. the interval between the outcome tone occurring due to their actions, and the followers action triggered by the tone. Their findings show that when our actions cause others to act, our sense of agency can increase, encompassing both our own actions and their consequences.

We can also see an increase in sense of agency when our actions cause certain social effects, such as a change in eye-gaze direction. These studies have found that when our actions cause another to attend to us, either by leading the eye gaze of another onto an object (Stephenson et al., 2018), or to look at us as opposed to away from us (Ulloa et al., 2019), we will experience an increased sense of agency. For example, Ulloa et al. (2019), conducted an adaptation of the intentional binding paradigm in which the participants button press would cause the image of a face to appear on a computer monitor

in front of them, who's eye gaze was either directed or averted to the participant. They observed increased intentional binding when eye gaze was directed. Moreover, Stephenson et al. (2018) found that intentional binding increased when participants lead the eye gaze of another. They have suggested that the ability to direct the eye-gaze of others allows us to detect, and understand, the social consequences of our actions (Stephenson et al., 2018). To elaborate, when others are attending to our actions, it indicates that our actions hold some value for them, increasing its perceived importance. This research thus shows how perceiving the social consequences of our actions can have a large effect on our sense of agency.

Along with eye-gaze, the emotional reactions of others can also be used to gauge the importance, and benefits or cost, of our actions. Researchers have conducted numerous studies using human emotional vocalisations (Christensen et al., 2016; Moreton et al., 2017; Yoshie & Haggard, 2013, 2017). These studies paired the outcome of an action with either a positive, or negative human vocalisation, or neutral sounds. It was observed that negative outcomes reduced, and positive outcomes increased, intentional binding (Christensen et al., 2016; Yoshie & Haggard, 2013, 2017). Thus, when our actions have positive, compared to negative, social consequences (i.e. lead to positive, compared to negative or neutral vocalisations) we may experience an increased sense of agency over them.

In sum, these findings have illustrated that the social context of an action has quantitative effects on our sense of agency. Understanding how these social factors alter our sense of agency is critical, especially given the link between sense of agency and responsibility, which means that any increase or decrease in sense of agency is likely to have a profound social impact. Along with social factors having clear quantitative effects on self-agency (the sense of controlling *your own* action and their subsequent outcomes), research also suggests that social factors can have *qualitative* effects on sense of agency. More specifically, it is becoming clear that when working co-operatively with others the *type* of agency we experience may alter. In these situations, we may come to feel a sense of joint-agency (see section 1.3.3). In the next section, research on the sense of agency during such actions shall be discussed.

1.3.2. Actions in a social setting: *qualitative* effects on the sense of agency

Whilst the *amount* of agency we experience may change when acting in a social setting, the *type* of agency we experience can also change. One situation in which this seems to occur is in the context of co-operative joint actions. These are situations in which one works together with another person in order to achieve a common goal. In such settings, we may experience a sense of agency over both our actions *and* the actions of others, as well as the shared goals.

The extent to which we feel shared, compared to self, control when acting with others has been assessed in studies by Bolt et al., (2016;2017). Bolt et al. (2016), asked pairs of participants to work together by depressing a key (producing a tone) in order to maintain the rhythm of a series of tones they had just heard. After each trial they were asked to "'Rate your feelings of control over the timing of the sequence" on a scale that ranged from 01 (shared control) to 99 (independent control)", therefore gauging if participants felt more self- or joint-agency during each trial. The researchers manipulated the extent to which participants had to co-ordinate their actions. In one block of trials they alternated depressing the key every time, in another they alternated after four key presses, and in a final they sequentially pressed the key. They observed increased shared control when participants were the second person to act. They also observed increased shared control when there was an increased need for participants to co-ordinate their action together. In a follow up study, Bolt and Loehr (2017) also assessed how the predictability of a co-agents actions would affect judgment of shared, compared to self, control. They used a similar design as discussed above, but rather than altering the order in which the key was pressed, they altered the predictability of the co-agent's key press. They observed that participants felt more shared control when the timing of their co-agents actions were more predictable. This suggests you are likely to feel greater shared control when you need to

co-ordinate your action with another (Bolt et al., 2016), and you are more able to predict your co-agents actions (Bolt & Loehr, 2017).

Along with individuals reporting less individual control when following the actions of another, others have observed a difference between explicit judgments of self-agency, and intentional binding, when following the movements of another. Obhi and Hall (2011a) completed an adaptation of the interval estimation style intentional binding paradigm, in which participants either initiated the depression of the space key of a keyboard themselves, or passively followed the movement of a co-participant onto the key. Intentional binding, and self-reports of agency, were recorded from participants, both when they initiated, and passively followed the action. The researchers found no difference in intentional binding between leader and follower roles, suggesting that participants experienced a sense of joint-agency over the event, regardless of their involvement. In contrast, only the leader explicitly reported a sense of agency. The results highlight how the type of agency we experience can change as a result of who acts first, even if by a millisecond. The researchers argue that, when acting with another, we experience a sense of **we-agency** over the joint action, even if we did not initiate the movement. We have previously described how the intentional binding measure can be used to assess our feeling of agency (Synofzik et al., 2008b). These results suggest that, when engaged in co-operative joint action,

the measure may represent changes in our feeling of agency that is *shared* with a coagent.

This idea may be supported by further research, conducted by Obhi and Hall (2011b), assessing our sense of agency when engaged in human-computer joint actions. Using a similar design to that described above, only with the coagent replace with a robotic arm, they observed significantly less intentional binding when following a robot compared to a human. Others have also found this reduction in intentional binding, even when unaware that the co-actor had been switched (Grynszpan, Sahaï, et al., 2019). Taken together, these findings suggest that there is something unique about interacting with another person, compared to a robot [1].

How different socio-environmental factors affect our sense of agency when acting with others has also been assessed. Le Bars et al., (2020) had pairs of participants complete a joint action. The task involved using a keyboard to move an on-screen cursor, which appeared in the centre of the screen, to one of four locations. One participant was able to move the cursor up and down, the other was able to move the cursor left and right. The researchers manipulated the amount of movement required from both participants, the congruency between the action and the movement of the cursor, and the fairness of rewards gained by each participant when

[1] In recent years there has been increased interest in the sense of agency during human-computer interaction, however a comprehensive review of this research is outside of the scope of the current thesis. For a review of this research see Sahaï er al. (2017).

completing the trial. Participants gave judgments of both individual and collective control after each trial. They observed that individual and collective judgements of control were affected equally by the congruency of their actions to the on-screen movement of the cursor, however the two measures were affected differently by the other two factors. Individual judgments of control were reduced when their involvement in the task was reduced, whilst collective judgements of control were improved when the outcome was shared fairly between participants. Thus, when involved in a co-operative joint task, different factors will affect both individual and collective aspects of our sense of agency.

In sum, these studies have shown how the *type* of agency we experience changes when interacting with others. In such settings the actions of our co-agent can alter both how much agency we experience, and also, whether we feel connected to the other person we are acting with. These actions require the interaction of sensory cues at multiple different conceptual levels, from understanding of the global purpose of a joint action, through to our prediction of the particular movements of our coagent. These extra factors are what alter the type of agency we experience. When acting alone our sense of agency allows us to make simple judgments of authorship and responsibility; was that me or was that not me. When acting with others a judgement must be made, not only of if oneself is responsible for a sensory event, but also, whether any of our coagents are responsible. During small

scale co-operative joint actions, the strength of our sense of agency will be dependent on the quality and reliability of our predictions regarding our own actions, and our coagents actions, as well as how well both agents' actions combined in order to achieve the desired outcome. When engaged in such action, our sense of agency can be divided into two complimentary parts; our sense of self-agency, which is akin to the sense of agency we experience during individual actions, and our sense of **joint-agency,** which is indicative of the extent to which we perceive the actions of ourselves, and our coagent, to be equal and commensurate (Pacherie, 2012). Theories which explain how self and joint agency interact, creating qualitatively different agency experiences, is what I shall now discuss.

1.3.3. Interpreting qualitative changes to the sense of agency: Joint agency

There is an almost in-exhaustible list of situations in which our actions can be considered as part of a, larger, group action. In each situation, the joint action will vary across a wide range of dimensions, from groups size, through to distribution of outcomes, each can have an effect on the phenomenology of the action and our agentic experiences of it. Pacherie, (2012) has suggested that we experience both a sense of self-agency and a sense of joint-agency when completing a joint action. She has also proposed how some sensory, social, and contextual cues may affect both aspects of our sense of agency. The current section will describe how different cues may affect our agentic

experience and relate this to the research previously discussed. Finally, areas still to be explored will be mentioned, and some suggestions for future directions shall be made.

Pacherie (2012) outlined several dimensions which may affect the phenomenology of joint action. Firstly, the number of people involved in a joint action may vary; when dancing at a music festival many thousands of people may be loosely involved in the collective action, whilst when dancing to music at home with friends, much fewer people are involved. Secondly, the group structure of a joint action can also vary, in some settings, such as the military, there is a clear hierarchy, whilst others, such as a festival, are more egalitarian. A third dimension relates to the specialisation of roles between coagents; those dancing to music may have little specialisation – all dancing freely at a festival – whilst the musicians on stage will have very specialised roles. A fourth dimension regards the physical nature of the joint action, in the modern world we may engage in joint action without physical proximity – due to covid-19 many of us are forced to work together virtually - whilst others involve a close physical proximity, such as when dancing. Also, people may be engaged in long-term, or transient joint actions; professional dancers may spend months perfecting a routine, whilst those at a festival may only dance together briefly. Finally, the extent to which our actions are regulated can also change, those at a festival dancing have large

amounts of freedom over their actions, whilst those marching in a military parade have their action entirely regulated by a larger institution.

These different dimensions can affect the amount and type of agency we experience over an action and its consequences. For individual actions, the extent to which we experience a sense of agency is largely dependent on the congruency between our prior representation of an action and outcome, and the physically observed event. However, when involved in a joint action, a prediction must be made, not only of one's own actions and their expected consequences, but also that of any co-actors, as well as how all actors actions relate to each other in terms of achieving the joint goal. Pacherie (2012) suggested a three-tiered hierarchy to encompass the different factors; Shared distal intentions, shared proximal intentions, and coupled motor intentions. Depending on the joint action being conducted coagents will share a representation of the joint action to differing degrees, and at different tiers of this hierarchy.

At the highest tier, individuals may have **shared distal intentions**, that is they must 1) be aware that they are working together to accomplish a joint goal, and 2) be able to adjust their sub-plans dynamically and in response to the other actor in order to accomplish the joint goal. One example of shared distal intentions may be when a log is blocking the road. Two individuals may both realise the log is blocking the road and that they will need to work together to be able to move it out the way (requirement 1 of shared distal

intentions), then be aware that as the other actor has grabbed one end of the log they will have to grab the other (requirement 2 of shared distal intentions) and lift together in order to move the log to the side of the road.

At the next tier, individuals may have **shared proximal intentions**, which indicates the ability of coagents to share their actions together effectively. Numerous mechanisms, that allow us to make predictions of coagents when involved in joint action, and to adapt dynamically in order to achieve shared goals, have been suggested. Firstly, in order to effectively complete a joint action, individuals must be engaged in joint attention towards the shared goal. This allows for the creation of a 'perceptual common ground', in which the minds of coagents with the same task representation become linked (Sebanz et al., 2006; Tomasello, 1995). It should be noted that joint attention is more than two agents simply attending to the same object. In order to be engaged in joint attention agents must understand that they are both attending to an object for some causal reason and be aware that the other is also attending to the object. For example, if two agents are looking at a painting without awareness that each other is looking at the painting, or know why they are looking at it, then they will not be considered engaged in joint attention.

Some joint actions, such as dance, require individuals to complete tightly synchronized motor actions. In such situations, individuals will share **coupled motor intentions**. Such situations require us to go beyond

understanding of the motor affordances of others, as our bodily self must become merged with that of the group. This ability to tightly co-ordinate our actions with another may sound cognitively taxing, however there is much evidence to suggest that we often complete such actions unconsciously. For example, researchers have observed that we unconsciously synchronize our movement on rocking chairs (Richardson et al., 2007), as well as mimic the posture of others when interacting (Chartrand & Bargh, 1999).

The sense of agency for joint action requires the interaction of sensory cues at each of these conceptual levels, from understanding of the global purpose of a joint action, through to our prediction of the particular movements of our coagent. These extra factors are what alter the *type* of agency we experience. They allow us to feel both self-agency over our own actions, and joint-agency over the shared goal. Depending on these factors we will experience differing levels of self and joint agency.

When engaged in joint action with another, where the contributions of all agents towards the joint goal is equal, and there is an egalitarian group structure, we are most likely to experience a large sense of joint agency. In such settings, we are also likely to experience a lack of self-agency due to the merging of the movements of others and ourselves (Paladino et al., 2010). The combination of high joint agency, with a lack of self-agency has been termed **we-agency**. In other situations, where there is less similarity between the movements of coagents, though the group structure is still egalitarian, and

the contribution of each coagent toward the group goal is equal, participants may still experience a sense of self-agency, as well as a sense of joint-agency. Pacherie (2012) termed such an experience **shared-agency.**

The difference between we- and shared-agency can be illustrated using the studies discussed in the previous section. For example, Obhi and Hall (2011a) showed that task order (whether first or second to act) had a significant effect on explicit reports of self-agency - with higher ratings when first to act - but not their implicit measure of agency (intentional binding). They argue that the results indicate the formation of a we-agency identity. Similarly Bolt et al (2016) found that participants experience more shared-control, and less self-control, when the second to act in a joint task. Considering both studies, task order may affect judgments of self-agency, but not joint-agency, leading to leaders and followers agentic experience differing; the first to act may experience shared agency – joint-agency plus self-agency - whilst followers may experience we-agency - joint-agency minus self-agency.

Bolt et al (2017) also showed the importance of co-ordination of action for the emergence of joint agency. When altering the degree to which participants had to consider the movement of their coagent, by having to alternate or sequentially complete key presses. They observed increased explicit reports of joint-control when participants had to alternate their actions, as predicted by Pacherie (2012). Her theory also predicted that our

agentic experience will be dependent on how actions are distributed between agents. The importance of this factor was assessed by Le Bars et al (2020). They observed the highest judgments of collective control when outcomes were shared fairly between coagents – i.e. based on the required input of each coagent –, compared to being shared equally, or all or nothing. However, the distribution of outcomes had less of an effect on individual judgments of control, which further illustrates how sensory and socio-environmental cues impact self-agency and joint-agency differently.

Some have even shown that we may experience a sense of agency over the actions of a coagent, even when we do not move. When we are involved in a joint goal (but not required to act), such that we have shared distal intentions, we may experience **vicarious-agency** (Sahaï et al., 2019; Wegner et al., 2004) over the others movements. Though interesting, the phenomenological form of vicarious agency is unclear due to differences in the interpretation of the concept. Sahaï et al (2019) have used the term vicarious agency to describe an implicit (intentional binding) sense of agency over the action of a coagent during a joint action task (joint Simon task). In contrast, Wegner et al (2004) use the term to describe an experience of embodying the actions of a coagent in a rubber hand illusion style experiment.

This disparity in the meaning of vicarious agency, can also be seen in other social agentic identities. One reason for this is the difference in methods used by researchers. Whilst some have used intentional binding, showing

similar findings for both actors during a joint action, others have used a variety of self-report measures. Some, such as Le Bars et al (2020), have asked separately about individual and joint experiences of control. Others have considered self and shared judgment of control as opposing ends of the same spectrum (Bolt et al., 2016), which does not allow for self and joint agency to be measured separately. As researchers have only begun to study agency during joint action such methodological and theoretical problems are to be expected. However, as more research is conducted it is hoped a better, more clearly defined, understanding of the phenomenology of joint action will be developed.

1.4. Conclusion

This introduction began by describing how our actions are tightly linked to our social world, whether it be to affect other people's behaviours, or the importance of being able to co-ordinate our actions with others. We then illustrated how the sense of agency allows us to track how in control we are of our actions and their effects, as well as the models which show how different sensory cues affect our sense of agency. The difference between implicit and explicit agency were explained and the research methods which can be used discussed - with special attention played to intentional binding. What these methods have told us about how our social world can affect our sense of agency when acting in isolation was outlined, before moving onto a

discussion of agency in joint action. How we can conceptualise agency in joint action, with distal, proximal, and motor intentions, was then outlined, as well as how the type of agency we experience changes when interacting with others.

The empirical research that follows aims to assess social aspects of agency in two parallel streams. In the first two chapters I will focus on how the social consequences of our actions effect our sense of agency. In the second two chapters the underlying physiology associated with agency during joint action with more tightly couple motor intentions will be assessed.

2. Social Impact and Agency

2.1 Study 1: Social outcomes

2.1.1 Introduction

When our actions impact others, whether financially, emotionally, or physically, we often imbue them with increased importance. An example of this increased importance can be seen in the military; does an officer commanding 30 troops feel the same amount of agency as one commanding 300, or 300,000? When our actions have social consequences, they must be considered at a higher conceptual level, as our sense of agency will also be affected by our prior relationship with those who are affected, as well as the effect the action has on them (Synofzik et al., 2008b). Previous research has shown that we can experience a sense of agency for both our actions and their social consequences (Pfister et al., 2014). However, little research has assessed how altering the social impact of our actions, in terms of number of people affected, may alter the sense of agency.

Some thoughts on how social impact may affect the sense of agency can be offered by looking at research on social power - the ability to influence other people's feelings, thoughts, or behaviour. People who have social power are typically confident, assertive, and feel an *increased freedom to act at will*, as well as a *reduced sense of accountability* (Guinote, 2017). Having a perceived increased freedom to act suggests that, when our actions have a

wider social impact, we may experience a larger sense of agency over our actions due to an increased background sense of control over our environment; i.e. a sense that your actions will also cause a *re-action* in others, and you will feel a sense of agency over those social consequences. In contrast, having a reduced sense of accountability suggests our sense of agency may be more dependent on their outcomes. Taken together, it appears that social impact may increase our sense of agency, and that outcome valence may also have an effect, though reliable predictions of its affect are harder to make.

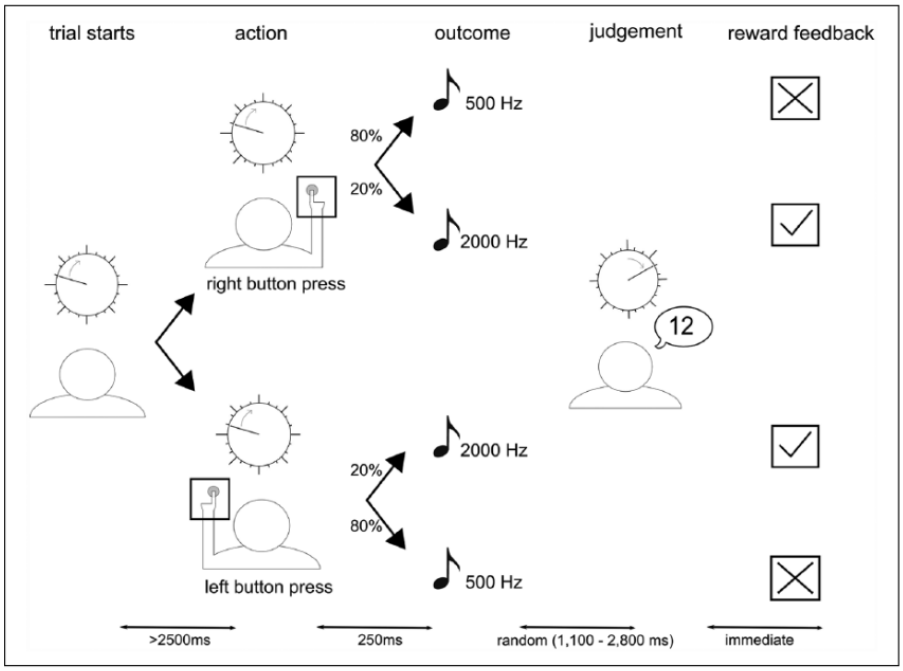
It could also be hypothesized that those who are affected by an action may experience a vicarious, or joint, sense of agency over the event. Previous research has shown that when observing a co-agent act, we may experience a vicarious sense of agency over their actions (Sahaï et al., 2019). However, it is not known how varying the impact of those actions influences the effect. When observing the actions of a coagent, you may expect to experience a vicarious sense of agency only when their actions affect you. Moreover, the experience could be sensitive to the valence of the outcome; feeling vicarious agency over positive, but not negative, events. Alternatively, if a joint-agentic state has been created between oneself and the other, as both yourself and coagent are considered two parts of an agentic whole (Pacherie, 2012), such vicarious agency experiences may not be sensitive to who is affected by an outcome. It has yet to be determined how our sense of agency changes when

observing an action which does, or does not, affect oneself. By manipulating whether we have a vested interest in an observed action we can further improve our understanding of how we cognitively associate with others.

One method that could be used to look at the effect of social impact on the sense of agency, is to adapt previous research looking at the effect of financially valenced outcomes. Di Costa et al. (2017) used a reversal learning paradigm which assessed the effect of valence on the sense of agency. In their study, participants were free to choose between pressing one of two keys - one key associated with an 80% chance of reward (and a 20% chance of loss) and the other key with a 20% chance of reward (and an 80% chance of loss; see Figure 5). The mapping of key press to reward probability switched once

Figure 5

Reprint of schematic of the experimental design used by Di Costa and colleagues (2017)



the high reward probability key had been pressed a variable (5<7) number of times. Using the Libet clock method (Haggard et al., 2002), they found that negative outcomes produced increased intentional binding on the following, but not the current trial, suggesting that reinforcement learning processes may be engaged in the ongoing computation of agency. The study illustrates that our sense of agency is affected by the financial consequences our actions have for ourselves. By adapting their study, so that others are also affected, we may be able to assess how we would feel when our actions financially impact others.

To conclude, knowing how our sense of agency changes as a function of the social impact our actions have, seems an important question that has yet to be answered. In order to answer these questions a "social gambling" experiment, which builds on the design of Di Costa et al. (2017), shall be conducted. The project has two key aims. Firstly, it aims to assess how our sense of agency is affected by the social impact of our actions. Secondly, it aims to assess how observing actions, which you do, or do not, have a vested interest in, affects your sense of agency. In relation to our first aim, our specific hypotheses are that a) intentional binding will increase for actions which have a wider social impact, and that b) social impact will interact with outcome valence, such that the effect of valence is increased for actions which have a wider social impact. In relation to our second aim, we predict that c) there will be an interaction between task involvement and social impact, such

that the effect of social impact is larger when observing an action. This final hypothesis was made because, when observing an action, participants were affected by events in one block of trial, but not the other. Therefore, we predict they will experience more agency (i.e. more intentional binding) over observed action which have a greater social impact (i.e. when observing actions they are affected by).

2.1.2. Method

Participants

A power analysis based on previous research (Khalighinejad et al., 2016; $F_{(2,59)} = 4.73$, $p = 0.01$, $\eta 2 = 0.14$) that assessed the effect of social observation on intentional binding, was conducted in G*Power 2.1 (Faul, Erdfelder, Buchner, & Lang., 2009) and gave a required sample size of 52. A total of 52 participants were recruited from the Goldsmiths community (37 Female, Age: 22 (2.9)). Participants completed the experiment as a pair, thus a total of 26 pairs of participants completed the study. Participants were reimbursed with course credit and £5 (maximum potential earnings).

Apparatus and materials

The experimental script was written in MatLab (2017a) and presented using a MacBook Pro (Early 2015). Speakers (Tsunami EA-60) were used to present the outcome tones. Three computer monitors were used for the study. A central (stimulus) computer monitor (Dell P2214H, 47cm/27cm), and two

peripheral computer monitors for response input (ViewSonic VA915, 38.5cm/30cm; MacBook Pro, 28.5cm/18cm). These peripheral monitors were occluded in such a way that they could not be viewed by the other participant (see Figure 6).

Two keyboards were used to input participants interval estimates (standard Dell Keyboard; MacBook Pro inbuilt keyboard). The keyboards were also occluded in a similar manner to the peripheral computer screens (see Figure 6) and a researcher sat behind the participants to ensure they did not communicate during the study.

Participants also completed a friendship questionnaire that asked about the relationship with the other participant prior to the study (See appendix 1).

Design

A within subject design with three factors was used. The first factor was Task; Active Task involved the subject actively pressing a key, Passive Task involved the participant observing their co-participant in the study pressing the key. The next factor was Condition; for Actor-affected Condition the Outcome of each trial affected only the Active participant, for Both-affected Condition the Outcome affected both participants. The final factor was Outcome; Win Outcome was associated with an increased chance of monetary gain, Lose Outcome was associated with a decreased chance of

monetary gain. It should be noted that although participants were led to believe that their payment was performance-related (so as to motivate and engage them in the task), at the end of the experiment participants always received the maximum potential earnings from the study and were fully debriefed.

Outcome was dependent on the action that the participant made and the associated probability of reward. Win outcomes were indicated by a 2000 Hz tone and lose outcomes were indicated by a 500 Hz tone. If the high reward probability key was pressed on between five and seven consecutive trials (randomised), the win/lose probability mapping would switch in two trials. The probability mapping also switched on trials 6, 10, and 14 of each experimental block, irrespective of which key was pressed.

The dependant variable was mean interval estimate in milliseconds. Mean interval estimates were computed by averaging each participants' interval estimates for each action-tone interval and each cell of the design.

Procedure

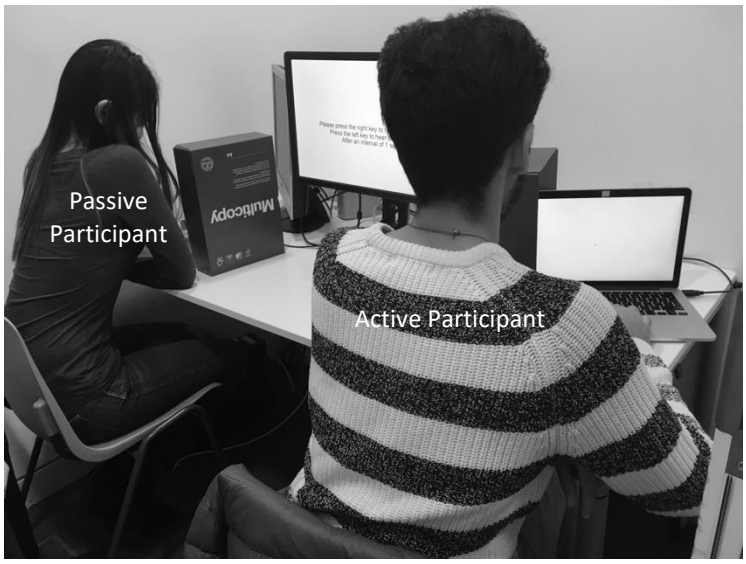
First, both participants independently gave written consent and completed the friendship questionnaire, after which they entered the test room and sat in the relevant position depending on their participant number – Odd numbered participants always began the experiment as the Active participants (see Figure 6).

Once seated, the Active participant pressed the right arrow key, which produced a 'Win' tone after 1 second, then they pressed the left arrow key, which produced a 'Lose' tone after 1 second. Participants were informed that the action-tone interval would never be more than 1 second. After completing the two 'warm-up' trials they began the first two experimental blocks; the Actor-affected and Both-affected Conditions for their Task (Active or Passive).

Each experimental trial began with a black dot appearing in the middle of the main screen (1000ms) during which the participant could not act. A fixation cross then appeared indicating that the Active participant could now

Figure 6

Picture of experimental set-up



Note. Picture shows location of active and passive participants, along with the position of central (stimulus) monitor and occluded peripheral (response input) monitors and keyboards for both participants.

press, either the left, or the right, arrow key of their keyboard. This produced a win, or lose, tone after the variable delay (300<700ms). Once the tone occurred the Active participant entered their interval estimate, after which the passive participant entered their interval estimate. Finally, a a notice appeared on the central monitor asking participants if they were happy with their answer. This was included to give participants a chance to re-enter their estimate if typed incorrectly. . Participants completed 54 trials per experimental block.

Both tones were presented for 100ms at 70 Decibels. In each trial, the action-tone interval was either 300, 500, or 700ms; six of each interval were presented pseudo randomly within each trial block. During experimental trials one key delivered a Win tone with a probability of 80% and Lose tone with a probability of 20%. The other key had the opposite Win/Lose tone probability mapping.

Once participants had completed two experimental blocks, they would switch seats. The new Active participant would then complete the same procedure as before; first performing the two 'warm-up' trials followed by the two experimental blocks (Actor- affected and Both-affected) for the other Task.

Once both participants had completed all four experimental blocks (Active Actor-affected, Active Both-affected, Passive Actor-affected ,

Passive Both-affected) they were fully debriefed and reimbursed for their participation.

Data Processing

Raw data outlier exclusion

For each participant, and within each action-outcome interval, interval estimations more than 3 standard deviations from the mean were removed (0.5% of trials).

Participant exclusion

In order to ensure that participants were able to distinguish the action-outcome intervals a one-way analysis of variance was conducted on each subject with interval length as the independent variable and interval estimate as the dependant variable. Any participants who did not show a significant difference between these intervals were removed. (17 participants). Any participants who failed to have a response at each interval and in each cell of the design were removed (3 participants).

2.1.3. Results

Interval Estimates

In order to assess the effect of Task, Condition, and Outcome on intentional binding, mean interval estimates for each condition were

subjected to a 2 (Condition: Actor-affected, Both-affected) x 2 (Task: Active, Passive) x 2 (Outcome: Win, Lose) ANOVA. No significant main effect of condition was observed (Actor-affected: M=440.42, SD=145.4; Both-affected: M=414.28, SD=140.43), $F_{(1,31)} = 2.332$, $p = .137$, $\eta_p^2 = .07$. This suggests that binding was similar when the action affected just the actor or both the participants.

No significant main effect of Task was observed (Active: M=418.28, SD=140.43; Passive: M=417.77, SD=150.52), $F_{(1,31)} = 2.332$, $p = .122$, $\eta_p^2 = .076$. This suggests that binding was no different when someone actively pressed the key or passively observed someone else pressing it.

A significant main effect of Outcome was observed, with interval estimates being shorter for Win (M=402.35, SD=139.63) compared to Lose (M=433.71, SD=151.32) trials, $F_{(1,31)} = 10.823$, $p < .05$, $\eta_p^2 = .259$. No significant interactions were observed. The mean and standard deviation of each cell of the design are presented in Table 1.

Table 1

Means and (standard deviations) of interval estimates for both Outcomes (Win and Lose) across the four experimental blocks.

Experimental Block	Outcome	
	Win	Lose
Active Actor-affected	430.47 (136.64)	467.96 (129.5)
Active Both-affected	457.28 (119.02)	491.5033 (145.9)

Passive Actor-affected	411.88 (115.28)	451.37 (117.48)
Passive Both-affected	417.18 (96.31)	449.4342 (112.02)

Post-Error Boost

As previous research has indicated that negative outcomes may cause a post-error boost to interval estimates (Di Costa et al., 2017), a repeated measures ANOVA was conducted which assessed the impact of outcome on the previous trial in a 2 (Condition: Actor-affected, Both-affected) x 2 (Task: Active, Passive) x 2 (PrevOutcome: Win, Lose). No significant difference was observed between Actor-affected (M=436.34, SD=119.47) and Both-affected (M=449.26, SD=111.7) Conditions ($F_{(1,31)}$ = .1.770, p = .192, η_p^2 = .054), Active (M=458.98, SD=125.3) and Passive (M=426.62, SD=105.88) Task ($F_{(1,31)}$ = 2.15, p = .086, η_p^2 =.092), or Win (M=447.93, SD=121.03) and Lose (M=437.66, SD=110.14) PrevOutcome ($F_{(1,31)}$ = 2.199, p = .148, η_p^2 = .066) was observed. No significant interactions were observed. The mean and standard deviation of each cell of the design are presented in table 2.

Table 2

Means and standard deviations (in brackets) of interval estimates for both PrevOutcomes (Win and Lose) across the four experimental blocks.

Experimental Block	PrevOutcome	
	Win	Lose
Active Actor-affected	452.52 (131.27)	443.01 (119.53)

Active Both-affected	480.82 (129.26)	459.57 (121.12)
Passive Actor-affected	429.42 (124.31)	420.40 (102.76)
Passive Both-affected	428.99 (99.3)	427.67 (97.14)

2.1.4. Discussion

The current study had two key aims. Firstly, to determine if our sense of agency is affected by the social impact of our actions. Secondly, to determine whether we experience a sense of agency over actions we observe, but have a vested interest in. In order to answer these questions an adaptation of an intentional binding study was used (Di Costa et al., 2017), in which task involvement, social impact, and outcome valence were manipulated.

In regard to our first hypothesis, we expected to see, either a main effect of social impact, or an interaction between social impact and outcome valence. A main effect of social impact would indicate that our sense of agency is affected by whether or not our actions have a wider social impact. An interaction between social impact and outcome valence would indicate that, when our actions have wider social consequences, the importance of its effect on the sense of agency changes. Neither a main effect of social impact, nor an interaction with outcome valence was observed.

In regard to our second hypothesis, we expected to see an interaction between task involvement, and social impact, with an increased difference between non-influence condition, where they are observing someone win

money only for themselves, and the social condition, where they are also earning money for them. This would indicate that, when observing actions, which we have a vested interest in, we feel a sense of agency over them. No interaction was observed.

Social impact was not shown to significantly interact with any of the other factors. Also, no main effect, or interaction with, task involvement was observed. A main effect of outcome valence was observed. Because our sense of agency measure was not affected by who was objectively affected by an outcome, or who was completing the actions, we tentatively suggest that participants were experiencing *joint agency* over the task, as has been reported in previous studies (Le Bars et al., 2020). A more in-depth review of the present findings shall now be given, followed by a discussion of limitations, and possible future studies.

As no effect of social impact was found, our primary hypothesis was rejected in favour of the null. This suggests that, when involved in joint action, our sense of agency, as measured by intentional binding, is not affected by the social impact of our actions. Moreover, as no interaction with task involvement was observed, whether or not we are affected by an action did not affect intentional binding. This disagrees with our second hypothesis. Both of these null effects are surprising given the importance of the social impact of our actions in everyday life.

One explanation for these findings is that social impact does not affect our sense of agency at this implicit, pre-reflective, level. It has been proposed that there are numerous conceptual levels which encompass the sense of agency (Synofzik et al., 2008b), and that implicit measures correspond to low level, pre-reflective, processing of our actions, whilst explicit measures relate to higher level, conscious, processing of our actions (Dewey & Knoblich, 2014; Moore et al., 2012). Though some researchers have shown differences in the weighting of sensory cues by implicit and explicit measures (Barlas & Obhi, 2014; Ebert & Wegner, 2010), a comprehensive understanding of how cues are weighted by different measures is far from being developed. The current results may indicate that social impact does not affect our implicit feeling of agency.

Another explanation, and one we feel is more probable, is that participants were experiencing a sense of *joint agency* over the task (Pacherie, 2012). If participants were experiencing joint agency - where participants *subjectively* experience a blending of agentic identities with another individual (Pacherie, 2012) – then it should be the case that who was *objectively* affected by the outcome in each block would not alter their implicit feeling of agency. Moreover, previous research has also shown that when the outcomes of a joint action are shared equally depending on involvement, participants will feel an equivalent amount of agency over them (Le Bars et al., 2020). As both participants were equally involved in the joint

task (i.e. they both had an equal number of trials in which to earn money for the group), it would be predicted for them to experience an equal amount of agency. This may explain the lack of effect of task involvement and social impact, where not only are agents required to monitor each other's actions, but also believe they are responsible for affecting the financial outcomes for each other.

In contrast, a main effect for outcome was observed, with increased intentional binding for win, compared to lose, outcome trials. Whilst prior research an effect of financially valenced outcomes on intentional binding, (Di Costa et al., 2017; Takahata et al., 2012), the current study is adds to this by showing an effect over a *chosen* action; i.e. choice of left or right key press. As the current paradigm was adapted from a prior study (Di Costa et al., 2017), which had not shown an effect of outcome valence, an explanation for this finding is needed. Perhaps importantly, Di Costa et al. (2017) did not look at social effects, i.e. they did not manipulate task involvement or social impact of outcome, and had participants complete the study individually rather than as a pair. It may be that the social context in our experiment facilitated outcome processing. The presence of another person has previously been shown to increase the weighting of outcome stimuli on intentional binding. Khalighinejad et al., (2016) conducted an intentional binding study in which participants were watched by another human, a robot arm, or no one. When the participants were observed by a human there was a progressive shift in

the perceived time of both action and outcome towards the time of the outcome, suggesting that the weighting of outcome cues on intentional binding gradually increased. In our study participants had much more interaction with the person observing (i.e. their co-participant), which could have increased the weighting of outcome cues on their binding judgments. As such, whilst the impact of other factors cannot be discounted, prior research indicates the presence of a coagent as having a large effect on the impact of outcome valence.

Another point of difference between the current study and Di Costa et al.'s is that we used the interval estimation paradigm, rather than Libet clock paradigm, to assess intentional binding. These two methods differ in the attentional processes they require. The Libet clock method involves visual attention in order to indicate the position of the clock hand at time of action, or tone. Whereas the interval estimation method requires participants to attend to the temporal interval between the two events, which may vary, unlike in the Libet clock method. The use of these different intervals may have nullified the effect of the preceding trial on their estimates as the two trials are likely to occur within a different temporal interval. Another issue is that the interval estimation task does not allow us to measure specific changes in action binding, which were observed in Di Costa et al.'s study – use of the interval estimation task may have masked changes in the experience of action in our participants.

One notable limitation of our study is the high attrition rate. We excluded 17 participants owing to their performance on the interval estimation task. The exclusions were based on a very stringent participant inclusion criterion; that there should be a significant linear increase in interval estimates across the three interval durations. We decided on this criterion a priori, in hindsight it was likely to be too stringent and likely resulted in our experiment being underpowered. Further research could use a less stringent rejection criteria in order to decrease the data attrition rate.

The hight attrition rate may also have resulted from participants not having a chance to practice the intentional binding paradigm. The procedure used in the study only included two practice trials. Commonly experiments include a larger block of practice trials. Considering the multi-factorial, and social, design of the current study, implementing an adaptation of practice trial block design used by Sahaï., etal (2019) may have also helped reduced the high attrition rate. In this study participants completed 20 practice trials before each experimental block. These trials involved an on-screen visual cue being presented to participants, which was followed by a tone after 200<2000ms. Participants then verbally indicated how long they believed the interval to be, after which the correct interval was presented to them on-screen. Conducting this procedure at the beginning of the experiment would have given a chance for subject's internal clock to be recalibrated to perceiving the shorted intervals, without greatly increasing the duration of the

study. To conclude, we have suggested the lack of effect of social outcome on sense of agency occurred due to participants developing a sense of joint agency. However, the current design does not allow us to draw firm conclusions in this regard. Therefore, in the following study we directly address this issue by manipulating the nature of the social relationship between partners. An outstanding question, and one that we turn to in the next study, is whether or not the nature of the social relationship impacts our sense of agency.

2.2. Study 2: Social dynamic

2.2.1. Introduction

Study 1 did not observe an effect of social impact on the sense of agency. We have suggested that this was due to participants forming a joint-agentic identity between coagents. This would mean that the outcome *subjectively* affected some part of the joint-agent, irrespective of who was *objectively* affected by the outcome.

Joint agency is most commonly experienced when individuals are working together in small egalitarian groups toward a shared goal (Pacherie, 2012). When individuals are competing, they should not experience joint agency, as their goals are diametrically opposed. If the formation of a joint agentic identity between coagents is the explanation for why social impact did not affect intentional binding in study 1, then the effect should be modulated by varying the social dynamic between coagents.

In order to determine if the effect of social impact was mediated by the social dynamic – causing the formation of a joint agentic identity between coagents – a follow-up study was conducted. The experimental paradigm from study 1 was replicated, but a social priming task was added before completing the experimental section. The social priming task aimed to make participants feel they were either co-operating, or competing, with their coagent. If joint agency can explain the observed effects of the previous study,

then the joint agency effects should be more pronounced in the cooperative vs. competitive conditions.

More specifically we make two main hypotheses. Firstly, we expect to replicate the main effect of outcome valence observed in study 1, with positive outcomes bound more than negative ones. Secondly, we expect that those engaged in in a competitive, compared to co-operative joint action will not experience joint agency, which will increase the effect of social impact on intentional binding. We therefore predict a three-way interaction between, social prime, social impact, and outcome valence.

2.2.2. Method

Participants

A power analysis based on previous research (Khalighinejad et al., 2016; $F_{(2,59)} = 4.73$, $p = 0.01$, $\eta 2 = 0.14$) that assessed the effect of social observation on intentional binding, was conducted in G*Power 2.1 (Faul, Erdfelder, Buchner, & Lang., 2009) and gave a required sample size of 51. A total of 52 participants were recruited from the Goldsmiths community (43 Female, Age: 22 (6.5)). Participants completed the experiment as a pair, thus a total of 26 pairs of participants completed the study. Participants were reimbursed with course credit and £5 (maximum potential earnings).

Apparatus and materials

The same materials as the previous study were used. The actual experimental scripts, as well as other information regarding the design, and the raw data for this experiment can be found in the OSF project page (https://osf.io/e5s7y/).

Design

A mixed factorial design was used. The between subject factor was Social prime and was dependent on whether participant pairs completed a co-operative, or competitive, priming task with their co-participant before completing the experiment. The Co-operative Social Prime involved playing a cooperative task with their co-participant. The Competitive Social Prime involved playing a competitive game with their co-participant. The within subject factors from the previous experiment, of Task involvement (Active, or Passive), Condition (Actor-affected, or Both-affected) were included.

The dependant variable was mean interval estimate in milliseconds. Mean interval estimates were computed by averaging each participants' interval estimates for each action-tone interval and each cell of the design.

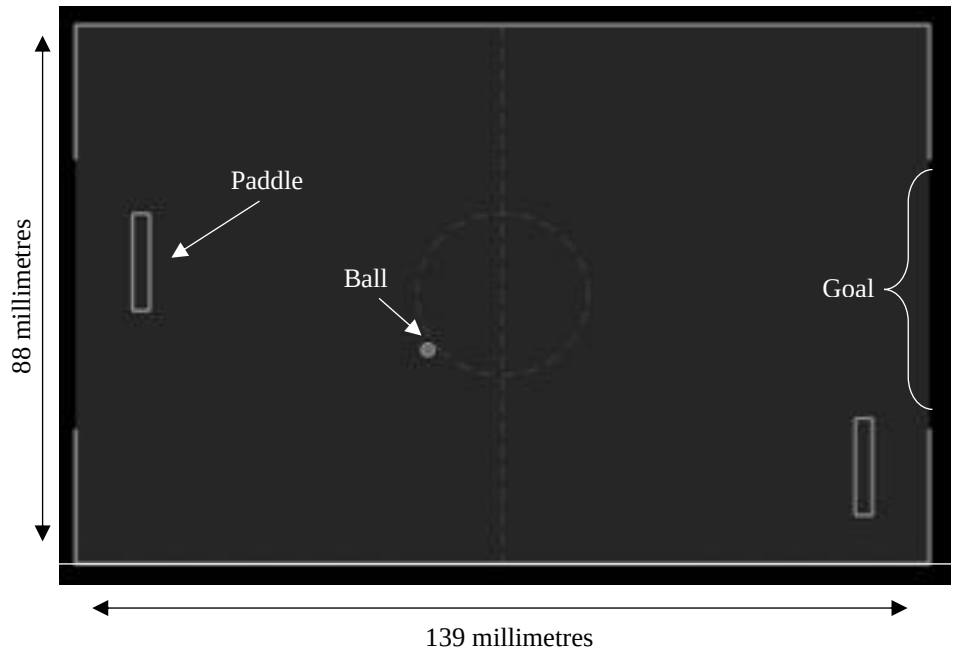
Procedure

First, both participants independently gave written consent. They then completed a computer based, and interactive, social priming task with

the other participant. For this we used an adaptation of the computer game Pong. In the game, participants move a *paddle* up and down in order to prevent a *ball* from entering the *goal* on their side of the court, and to try and get the ball to enter their opponents' goal at the other end of the court (See Figure 7). The participant sitting on the left-hand side of the screen pressed 'A' to move their paddle up, and 'Z' to move their paddle down. The participant sitting on the right-hand side pressed 'up-arrow' to move their

Figure 7

Image of social priming task with annotations showing the dimension of the court and position objects.



Note. The same task was completed by both co-operative and competitive groups. Participants use the Paddle to hit the Ball into their opponents Goal.

paddle up, and ‘down-arrow’ to move their paddle down. The paddles were designed in such a way that they stayed in motion (either moving up or down) until reaching either vertical edge of the *court*. At the beginning of each point both the paddle and the ball moved at the same speed, however the ball increased in speed by 5% every time it was hit.

The competitive group played the classic version of the game; each participant aiming to get the ball into the opponents’ goal. Before playing the game, participants in the competitive group were informed that a leader board of all scores was being kept and that the participant with the best score would receive an extra five pounds once testing was completed. The co-operative group were told to work together in order to get the longest rally they could by moving the ball back and forth between their markers. Before playing they were informed that a leader board of rally lengths was being kept and that the pair with the longest rally would receive an extra five pounds once testing was completed. Participants then completed two five-minute rounds of the social priming task.

Participants then completed an interval estimation task. The active participant was told to depress the right arrow key, which caused the ‘win’ (2000 Hz) tone to occur after one second. They then depressed the left arrow key, which caused the ‘lose’ (500 Hz) tone to occur after one second. This gave participants an opportunity to gauge how long one second was, and to allow them to hear the ‘win’ and ‘lose’ tones.

They then completed four blocks of 54 trials with the same design as the previous study with two changes. If the high reward probability key was pressed a certain number of consecutive trials (between 5 and 7 consecutive key presses, randomised), the win/lose probability mapping would switch in on the next trial. The action-tone intervals were 100, 400, and 700ms.

Data Processing

Participant exclusion

For each participant their grand mean estimate for each of the 3 action-tone intervals was computed. Any participants who failed to show a monotonic relationship between the 100ms to 400ms and 400ms to 700ms intervals were removed (16 participants). Any participant who failed to have a response at each interval for each cell of the design were removed (0 participants).

2.2.3. Results

Interval Estimates

In order to assess the effect of Social Prime, Task, Condition, and Outcome on intentional binding, mean interval estimates for each condition were subjected to a 2 (Social Prime: Competitive, Co-operative) x 2 (Condition: Actor-affected, Both-affected) x 2 (Task: Active, Passive) x 2 (Outcome: Win, Lose) ANOVA. No significant main effect of Social Prime

($F_{(1,30)}$ = 2.113, p = .156, η_p^2 = .066) was observed, with interval estimates being shorter for the competitive (M=428.74, SD=157.42) compared to co-operative (M=503.2, SD=179.88) condition.

There were also no significant differences between Actor-affected (M=470.31, SD=175.78) and Both-affected (M=465.04, SD=164.01) Conditions ($F_{(1,30)}$ = .356, p = .47, η_p^2 = .018), or Active (M=460.7, SD=164.34) and Passive (M=480.55, SD=182.47) Task ($F_{(1,30)}$ = .637, p = .431, η_p^2 =.021).

A significant main effect of Outcome ($F_{(1,30)}$ = 28.936, p < .001, η_p^2 = .491) was observed, with interval estimates being shorter for Win (M=428.74, SD=157.42) compared to Lose (M=503.2, SD=179.88) trials.

The predicted interaction between Social Prime, Condition, and Outcome was not significant ($F_{(1,30)}$ = 0.047, p = .829, η_p^2 = .002).

There was a significant two-way interaction between Task and Outcome ($F_{(1,30)}$ = 5.604, p < .05, η_p^2 = .157), with outcome having a larger effect for passive compared to active conditions (See table 3).

A three-way interaction between Task, Outcome, and Social Prime ($F_{(1,31)}$ = 4.578, p < .05, η_p^2 = .132) was also observed. In order to aid interpretation of the interaction independent post-hoc analyses of variance were conducted on co-operatively and competitively primed groups. Means were adjusted to account for type 1 error.

For the *competitive group*, the main effect of task was non-significant ($F_{(1,14)} = 0.158$, $p = .695$, $\eta_p^2 = .012$). A significant main effect of outcome was observed ($F_{(1,14)} = 19.192$, $p < .001$, $\eta_p^2 = .596$). A significant interaction between Task and Outcome was observed ($F_{(1,14)} = 6.893$, $p < .025$, $\eta_p^2 = .346$; See figure 8a).

For the *co-operative group*, the main effect of task was non-significant ($F_{(1,17)} = 0.563$, $p = .463$, $\eta_p^2 = .032$). A significant main effect of outcome was observed ($F_{(1,17)} = 8.841$, $p < .01$, $\eta_p^2 = .342$). The interaction between Task and Outcome was non-significant ($F_{(1,17)} = 0.039$, $p = .846$, $\eta_p^2 = .002$; See figure 8b).

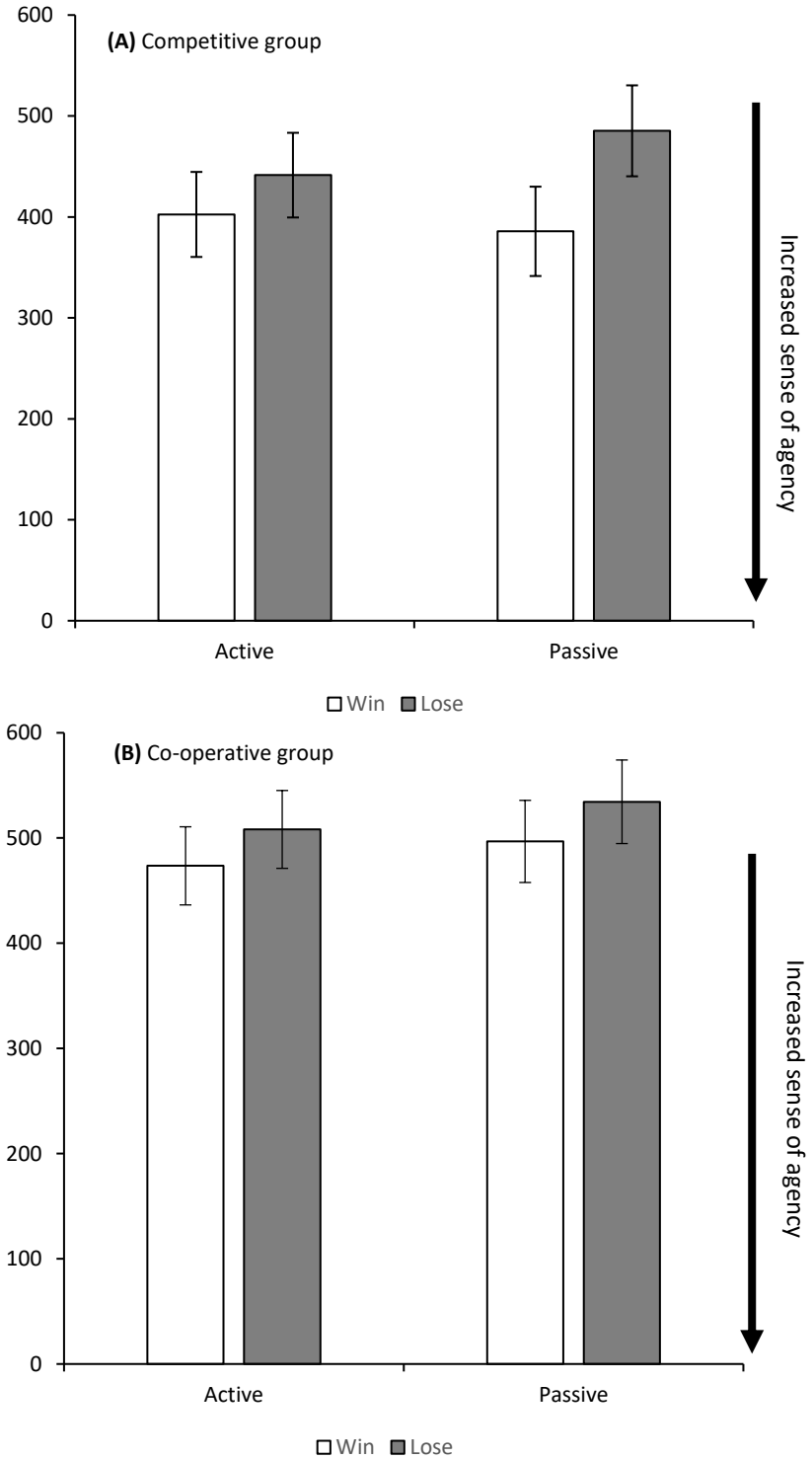
Table 3

Means and Standard Deviations for active and passive Task across both Social Prime groups

Task	Outcome			
	Win		Lose	
	M	SD	M	SD
Active	438	162.51	474.77	161.88
Passive	441.23	168	509.86	182.2

Figure 8

*Bar Graph of Task*Outcome interaction for Competitive and Co-operative social prime groups*



Note. (A) Interaction for competitively primed group. (B) Interaction for co-operatively primed group. Error bars indicate standard error.

2.2.4 Discussion

The current study aimed to determine whether our sense of agency during a joint action is mediated by the perceived social dynamic between individuals. We have suggested that the lack of effect of social impact observed in Study 1 was due to participants experiencing joint agency over the actions. This nullified any effect of social impact as the outcome was subjectively shared between participants, irrespective of who was objectively affected. If participants were not engaged in joint agency, then who was being affected by the outcome would have a larger effect on the sense of agency. As such, we had two key hypotheses for the current study. Firstly, we expected to replicate the main effect of outcome valence observed in study 1. Secondly, we predicted a three-way interaction between social prime, social impact, and outcome valence.

We did not observe the predicted three-way interaction. However, a two-way interaction between task involvement and outcome valence was observed, and a three-way interaction between social primes, task involvement, and outcome valence was also observed. Thus, although the expected interaction was not observed, the results do suggest that co-operatively primed participants were experiencing joint agency, whilst competitively primed participants did not. We will now elaborate further on how the reported findings relate to our two experimental hypotheses, then, expand to a discussion of the other observed effects and their implications.

Finally, we will outline the limitations of the study, as well as future directions for social agency research.

Finding a highly significant main effect of outcome valence, with increased intentional binding being observed for win outcomes, replicates the findings from study 1, indicating that when engaged in a joint action, outcome valence has a large effect on the sense of agency. This replicated result differs from those observed by Di Costa et al. (2016), where the participants completed the task independently. No post-error boost to agency was observed in the current study. Di Costa et al. (2016 had used the Libet clock method of assessing temporal intervals, whilst the current study implemented the interval estimation method. The Libet clock method allows for action and outcome binding to assessed separately, allowing for a more nuanced assessment of people temporal perception to be made. This difference in methodologies, along with the social nature of the study (see below) are likely factors for the lack of replication.

As discussed in sections 2.1.4, the observed findings do support previous research which has found outcome events to have a larger weighting on our sense of agency over time (Khalighinejad et al., 2016). The current study adds to this, suggesting that when our actions are nested in a social context, the weighting of outcome valence on our implicit sense of agency may increase. That is to say, when our actions are conducted in a social

context the *valence* of an outcome will play a larger role on our feeling of agency.

In regard to our second hypothesis, we did not observe the predicted three-way interaction between social prime, social impact, and outcome valence, thus the hypothesis was rejected in favour of the null. Moreover, social impact did not have a significant effect on intentional binding, with no significant main effect, or near interaction with other variables. This was not expected and suggests that when interacting with others, the implicit sense of agency we feel over our actions is not affected by their social impact. We had hypothesized that this was due to the social dynamic between participants, though we failed to find support for this argument.

One reason for this could be that social cues do not impact the sense of agency at an implicit level. As has previously been discussed, there are different conceptual levels to the sense of agency, and it has been argued that implicit measures may related to our lower level feeling of agency. The sense of agency at this level may not be affected by changes in the social impact of an action.

Another explanation may be that, as participants had an equal opportunity to act in order to financially aid themselves and their coagent, any effect of social impact was nullified. Previous research has already shown that when outcomes are shared fairly between participants individuals experience a large amount of joint agency (Le Bars et al., 2020). Thus, when

engaged in reciprocal joint action with another, with equality of outcomes, who is objectively affected by the outcome on each trial may not have affected the sense of agency, even when primed to view the other as an opponent.

Expanding to a discussion of the other observed results may offer further explanation for why social impact did not affect intentional binding. A three-way interaction was observed between social dynamic, task involvement, and outcome valence. Post-Hoc analyses showed that the interaction was driven by a significant difference between active and passive condition in the competitively primed group, with a larger effect of outcome valence when passively, compared to actively involved in the trial. Whilst we did not observe our predicted interaction this finding does suggest that when not experiencing any agency over an event, as would be expected in the passive competitive group, the weighting of sensory cues changes. Therefore, when not experiencing joint agency, intentional binding over observed events is driven more by their valence. This could be seen as indicative of intentional binding being more indicative of causality when participants are not experiencing a sense of agency over the event (Buehner & Humphreys, 2009). In contrast, when experiencing joint agency – i.e. co-operatively primed group - it appears that outcome valence has a similar effect when both actively and passively involved in the task.

Co-operatively primed participants also reported lower levels of intentional binding throughout the study. Though non-significant, there is a weak trend in this direction. This may indicate, as has already been reported with explicit measures of agency in joint action (Bolt et al., 2016), that agency over the event is shared between the participants. However, as only a trend was observed, the evidence to support this effect is weak.

Whilst the observed results are interesting, there are a number of limitations with the current study. Firstly, as with study 1, we did not control for the prior relationship between participants. As the majority of participants were first year undergraduate psychology students at the same institution, they were likely to have interacted with each other prior to the study. This lack of control was due purely to pragmatic constraints on our sample pool, funding, and time. It would be interesting to see whether a similar effect would be observed in a participant sample in which coagents were completely naïve to each other. Also, our attempts to reduce the attrition rate, by using a less stringent removal criteria (monotonic relationship between 3 action-tone interval lengths, rather than significant effect of interval in one-way ANOVA) and increasing the temporal distance between action tone intervals from 200ms to 300ms, only had a minimal effect. Thus, the study was also underpowered.

Nonetheless, these issues do not warrant a complete rejection of the observed findings, and some interesting conclusions can be drawn from the

study. Firstly, when our actions are placed in a social context, outcome stimuli appear to have a larger effect on intentional binding. Also, it appears that the measure is also affected by the perceived social dynamic between actors, though further research will be needed to improve understanding of this effect. In sum, the current findings indicate that when coagents are engaged in a joint agentic identity, effects are experienced at the group level, and that such an identity occurs during co-operative, but not competitive joint action.

3. Pro-social actions

3.1 Introduction

Having a positive impact on others is considered one of the main hallmarks of living a fulfilling and happy life. This view has been held throughout history, with many of our greatest minds venerating the helping of others. Plato believed that those who give great service unto others should be held up as role-models, whilst Marcus Aurelius stated, "people exist simply to help one another" (Hammond & Clay, 2006).

Despite the ubiquity and importance of such actions, it is only recently that pro-social behaviour has become a popular area of research in psychology. This research has shown the many implicit benefits of acting pro-socially. For example, researchers have discovered that those engaging in pro-social behaviour, such as volunteering, live longer, healthier, lives (Yeung et al., 2017). Similarly, spending small amounts of money on others, compared to oneself, has been shown to increase our happiness, even on subsequent days (Dunn et al., 2008). These researchers have shown how producing actions that have positive social consequences, benefits both our mental, and physical, health.

However, researchers have yet to assess how such actions can affect our sense of agency. Whilst there has been some suggestion that individuals who feel an increased sense of agency over their actions will increase their charitable giving (Aknin et al., 2011), the link between pro-social spending

and the sense of agency has not been experimentally studied. Such actions differ from those produced in first experimental section of the current thesis. These studies looked at how altering the *social impact* of an action may affect the sense of agency, though the action always affected the actor. Though similar, these actions tie into concepts of social power, whilst *pro-social* actions are more related to the extent to which we empathise and feel compassion for others.

The previous studies were also nested in a social context, with pairs of participants earning money for either themselves, or both themselves and their co-participant. It was suggested that the observed findings were due to participants experiencing a sense of joint agency (Pacherie, 2012). We argued that, due to the formation of a subjective joint agent between the participants, it did not matter who was affected by the outcome – their sense of agency was the same. When experiencing joint agency, external sensory cues can have a larger impact on the sense of agency, contributing to the observed significant effect of outcome valence in the previous two studies. When acting independently, and thus not experiencing a sense of joint agency, the weighting of sensory cues may change, with action cues having a larger impact (Moore & Fletcher, 2012).

The weighting of sensory cues may also be affected by how the sense of agency is measured., with some research finding outcome valence to have a significant effect on explicit, but not implicit, measures (Barlas et al., 2018).

In contrast, implicit measures have been affected by emotionally valenced outcomes (Christensen et al., 2016; Moreton et al., 2017; Yoshie & Haggard, 2013, 2017). Nonetheless, whether the social impact of an action has a different effect on our implicit and explicit sense of agency has yet to be determined. Often people wish for their pro-social actions to be explicitly recognised and observed by others. Such a desire for explicit recognition could lead people to exaggerate how responsible they were for such actions, though how this corresponds to implicit and explicit measures of agency is harder to determine.

In light of this we conducted the present study in order to assess how producing pro-social actions affects our sense of agency when acting alone. In this study participants acted in isolation, with the outcomes affecting *either* themselves, *or* another. In order to gain a holistic understanding of how pro-social actions affect the sense of agency, both implicit and explicit measures were taken. In line with previous studies on the effect of financially valenced outcomes on intentional binding (Barlas et al., 2018), we predict that a significant effect of outcome valence will be observed for both our explicit, and implicit measures. Regarding social impact, as prior research on pro-social behaviour has suggested a correlation between such actions and our sense of agency (Aknin et al., 2011), we predict participants will experience an increased sense of agency over pro-social, compared to self-interested action, with social impact effecting both implicit and explicit measures.

3.2 Method

Participants

A total of 24 participants were recruited from the Goldsmiths community (17 Female, Age: 23.38 (4.08)). This was indicated to be the appropriate sample size following a power analysis. This was based on the effect size from a 2 (beneficiary: Self/Group) x 2 (Outcome: Win/Lose) ANOVA conducted on data from a previous experiment (Chapter 2, study 2; $F_{(1,23)}$= 5.415, p = .029, η_p^2 = .19). Participants were reimbursed with course credit and £5 (maximum potential earnings).

Apparatus and materials

The experimental script was written in MatLab (2017a) and presented using a MacBook Pro (Early 2015; 2.7 GHz Intel Core i5; 8 GB Ram; OS Sierra 10.12.6). Speakers (Tsunami EA-60) were used to present the outcome tones. A computer monitor (Dell P2214H, 47cm/27cm) was used for presentation of stimuli. Standard Dell Keyboard and mouse were used for participant input. Data were analysed using SPSS (IBM SPSS, 2015). The experimental scripts, raw data, SPSS dat files, and further information regarding the design for this experiment can be found in the OSF project page (https://osf.io/9kgmb/).

Design

A within subject's design was used. The first factor was Condition; in the *Self-interested* condition the Outcome of each trial affected the participant's potential earnings from the study, in the *Pro-social condition* the outcome affected the potential earnings of the participants chosen beneficiary (who would come and collect their winnings at a later date). Participants completed one block of self-interested and one block of pro-social trials. The order of trial blocks was randomised using a Latin Square method.

The second factor was Outcome; *Win Outcome* was associated with an increased chance of monetary gain; *Lose Outcome* was associated with a decreased chance of monetary gain. It should be noted that although participants were led to believe that their payment was performance-related (so as to motivate and engage them in the task) participants, and their chosen beneficiary, always received the maximum potential earnings from the study and were fully debriefed.

The outcome was dependent on whether participant pressed the right or left arrow key, and the associated probability of reward. Win outcomes were indicated by a high (2000 Hz) tone and the word 'Win' appearing on screen. Lose outcomes were indicated by a low (500 Hz) tone and the word 'Lose' appearing on screen. Both tones were presented for 100ms at 70 Decibels. If the high reward probability key was pressed between five and seven consecutive trials (randomised), the win/lose probability mapping

would switch on the next trial. The probability mapping also switched on trials 6, 10, and 14 of each experimental block, irrespective of which key was pressed.

There were two dependant variables; mean interval estimates and self-report control ratings. Mean interval estimates were computed by averaging each participants' interval estimates for each action-tone interval and each cell of the design. Self-report control ratings were computed by averaging each participants' control rating for each cell of the design.

Procedure

First, both participants independently gave written consent. They then sat in front of a computer screen monitor, keyboard and mouse. Participants then indicated who their chosen beneficiary would be, and why they were choosing them.

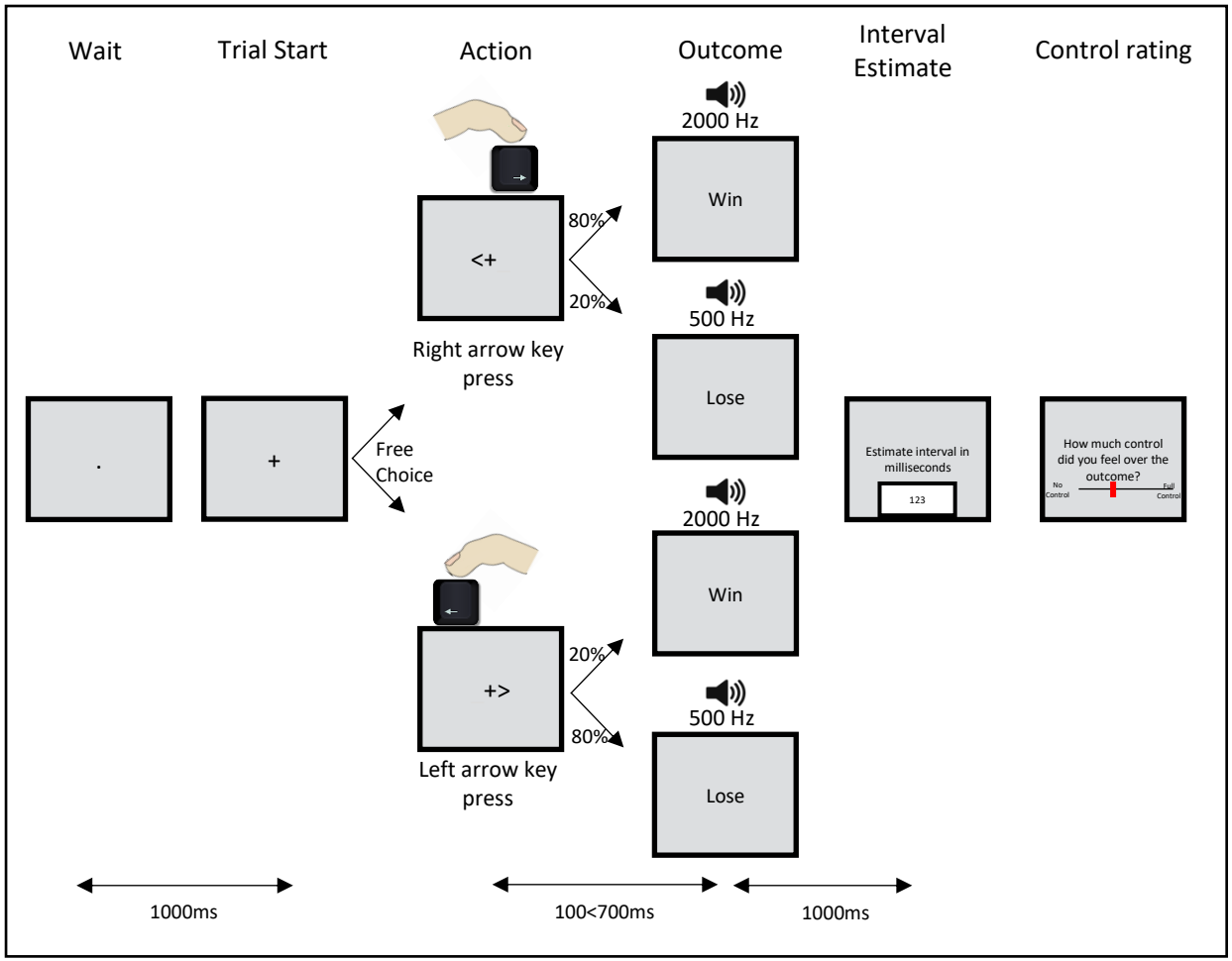
They then completed 9 practice trials. Each trial began with a black fixation cross. They could then press, either the left, or the right, arrow key of their keyboard. Once either button was pressed, and after the variable delay (100<700ms), the win or lose, tone outcome was played and the word 'Win', or 'Lose', presented on screen for one second. The fixation cross then re-appeared indicating the start of the next trial. Once all the practice trials were completed participants were informed that the action-tone interval would never be more than 1 second and given a chance to ask any questions.

Two blocks (one of each Condition; Self-interested, and Pro-social) of 45 experimental trials were then completed. Each trial began with a black dot appearing in the middle of the main screen (1000ms) during which the participant could not act. A fixation cross then appeared indicating they could now press, either the left, or the right, arrow key of their keyboard. Once either button was pressed the outcome stimulus would be presented as in the practice trials. They were then instructed on-screen to 'Estimate interval in milliseconds' (typing in their estimate then pressing enter). They then viewed a horizontal slide bar with the phrase 'No Control' at the left-end and the phrase 'Full-control' at the right-end (response was between 0 to 100 respectively). They were instructed, on-screen, 'How much control did you feel over the outcome?' and they could move the mouse to slide the cursor the bar to indicate their rating of control (see Figure 9).

In each trial, the action-tone interval was either 100, 400, or 700ms; 15 of each interval were presented pseudo randomly within each trial block. During experimental trials one key delivered a Win tone with a probability of 80% and Lose tone with a probability of 20%. The other key had the opposite Win/Lose tone probability mapping.

Figure 9

Illustration of experimental paradigm



Note. Each trial started with a 1000ms pause in which no action could be made, the participant was then free to choose whether to press the left or right arrow key of the keyboard which then, depending on the probability

3.3. Results

Interval Estimates

In order to assess the effect of Condition and Outcome on intentional binding, mean interval estimates for each condition were subjected to a 2 (Condition: Self-interested, Pro-social) x 2 (Outcome: Win, Lose) ANOVA.

No significant main effect Outcome ($F_{(1,23)} = .584$, $p = .45$, $\eta_p^2 = .025$) was observed, although interval estimates were slightly shorter for the Lose (M=492.67, SD=236.54) compared to Win (M=509.6, SD=236.54) condition.

A significant main effect of Condition ($F_{(1,23)} = 4.247$, $p < .05$, $\eta_p^2 = .161$) was observed, with interval estimates being shorter for Self-interested (M=467.237, SD=213.41) compared to Pro-social (M=535.026, SD=270.3) trials. This was contrary to our initial hypothesis.

The interaction between Condition and Outcome was not significant ($F_{(1,23)} = .22$, $p = .644$, $\eta_p^2 = .009$).

Self-report control ratings

A 2 (Condition: Self-interested, Pro-social) x 2 (Outcome: Win, Lose) ANOVA was conducted on self-reports of agency. A significant main effect Outcome ($F_{(1,23)} = 43.926$, $p < .001$, $\eta_p^2 = .656$) was observed, with ratings of control being higher for Win (M=53.07, SD=22.92) compared to Lose

(M=37.633, SD=18.92) condition. This was consistent with our initial hypothesis.

No significant main effect of Condition ($F_{(1,23)} = .329$, $p = .57$, $\eta_p^2 = .014$) was observed, Pro-social (M=45.866, SD=20.69),Self-interested (M=44.844, SD=21.16). This was contrary to our initial hypothesis. The interaction between Condition and Outcome was not significant ($F_{(1,23)} = .008$, $p = .927$, $\eta_p^2 < .001$).

3.4. Discussion

The current study assessed how the pro-sociality of our actions alters our sense of agency when acting alone. Our previous studies (Chapter 2), assessed how the social impact of action affects the sense of agency when acting with others. However, those studies did not examine pro-social actions – those actions that *only* benefit someone else. Our current study was designed to address this. In this way, we measured intentional binding and self-reported agency as participants attempted to earn money for themselves, or a chosen beneficiary.

We observed a main effect of social impact on intentional binding, with increased binding in the self-interested, compared to pro-social, block. No effect of outcome valence, or interaction, was observed. These findings, which contradict our initial hypothesis, suggest that the presence of a coagent may have affected intentional binding in the prior experiments, and that we

experience more agency over self-interested, compared to pro-social actions when acting alone. A main effect of outcome valence was observed for self-reports of agency (consistent with our initial hypothesis), with higher ratings for win, compared to lose, outcome trials. No effect of social impact, or interaction, was observed for self-reports of agency. This suggests that when acting alone, our conscious judgements of control are driven by trial-by-trial changes in the valence of their outcomes, rather than changes in the social consequences of an action, which were dictated at the beginning of each trial block. The observed results will now be explained in more depth, limitations outlined, and future research suggested.

Firstly, increased intentional binding was observed when participants were completing self-interested, compared to pro-social, actions. This suggests that, at an implicit level, we take more agency over actions when they affect oneself, compared to another. Considering the positive effect that pro-social actions have (Helliwell & Aknin, 2018), this result is unexpected, and disagrees with our hypothesis. One explanation could be that the current study differs greatly from real-world experiences of pro-social spending, in which the decision to act pro-socially is volitional. When our decision to act pro-socially is not voluntary, as was the case in the current study, the positive effects of such action for the actor are often negated (Choshen-Hillel & Yaniv, 2011). As participants were only able to choose the beneficiary of their actions, and not whether they wished to act pro-socially, the effect suggests

people experience more agency when earning money for themselves, compared to others. If participants were to act pro-socially, of their own volition, increased intentional binding may be observed in the pro-social block. Such a sample group may also be more dependent on the valence of their outcomes, though further research is needed to answer these questions.

It has also been suggested that intentional binding is related to instrumental learning. Instrumental learning involves learning the relationship between ones actions and their effects on the environment, which may then alter the probability that the action will be repeated (Walsh & Haggard, 2013). It has been observed that intentional binding is also dependent on learning the relationship between ones actions and their outcomes. For example, one study has illustrated that once participants had learnt that their actions produced a tone, they would perceive the time of the action as being shifted towards the tone, even on trials in which the tone did not occur (Moore & Haggard, 2008). What has not been assessed is the importance of self-relevance for instrumental learning to occur. It may be that instrumental learning mechanisms are primarily driven by outcomes which affect *oneself*, which would explain the observed increased in intentional binding for self-interested actions.

No effect of outcome valence was observed on intentional binding. This differs from the results of chapter 2 of this thesis, but replicates the null effect reported by Di Costa et al., (2016). We suggested in the previous

chapter that a joint agentic identity had been formed between coagents, and that this joint agentic identity had affected the weighting of sensory cues. When acting with another agent the impact of outcome signals on intentional binding – related to our implicit feeling of agency (Synofzik et al., 2008b) - thus appears to increase. In the current study, in which participants acted alone, no joint-agentic state was formed, thus reducing the impact of outcome valence. Instead, intentional binding was affected by action related signals; i.e. who was affected by the *action* rather than the valence of the *outcome*. This agrees with cue-integration models of the sense of agency which suggest that, when acting independently our sense of agency is primarily driven by action, rather than outcome, sensory signals (Moore & Fletcher, 2012).

In contrast, explicit reports of agency showed a large effect of outcome valence, with no effect of social impact. As stated earlier, participants were not able to control whether their actions affected themselves or their chosen beneficiary but did have some control over the outcome; they could choose whether to press the left or right key, which affected the probability of getting a positive or negative outcome. Self-reports of control appear to mirror this, indicating the perceived level of objective control they had over the outcome on a trial-by-trial basis, rather than the, phenomenologically more complex, sense of agency they were experiencing over the event as a whole. Stated simply, on a trial-by-trial basis, they had some control over outcome valence, reflected in their ratings, but had no

control over the beneficiary, thus not reflected in their ratings. Further research could switch social impact and outcome valence, so that outcome valence was blocked, and social impact was dependent on the participants actions. This would allow us to determine whether, as suggested, the observed effect is reflective of the objective level of control participants have over the task, or that, instead, objective reports were driven by valence, rather than beneficiary,

In sum, three key findings can be taken from the current study. Firstly, we implicitly feel more agency over actions which affect ourselves, compared to others. Secondly, when acting alone outcome signals have a reduced impact on intentional binding. Thirdly, explicit reports of control will be driven by immediate valence of sensory outcomes, rather than social situational factors; i.e. who is affected by the outcome. Further research could assess the influence of social impact when participants have a greater level of control over who will be affected.

4. Implicit and explicit measures in a social context

4.1. Introduction

In recent years there has been increased interest in the phenomenology of joint action, with a particular focus on the amount of control people experience (Bolt & Loehr, 2017; Dewey et al., 2014; Dewey & Carr, 2013; Le Bars et al., 2020; Pfister et al., 2014; van der Wel et al., 2012). Numerous factors, such as task order (i.e. first or second to act; Dewey & Carr, 2013; Pfister et al., 2014), the amount of co-ordination required (Bolt et al., 2016), and our ability to co-ordinate actions together (Bolt & Loehr, 2017) being shown to affect participants' experiences of control.

Along with changing the amount of control we experience, in some joint actions the type of agency we experience may also change. More specifically, when engaged in egalitarian joint actions, where both agents are contributing equally towards a shared goal, we may also experience a new agentic identity, such that the actions (and outcomes) of all agents involved in the shared goal are considered part of a conceptual joint agent (Pacherie, 2012).

More recently, researchers have sought to understand the relationship between these two agentic identities (self-agency and joint-agency). Research conducted by Bolt et al (2016; 2017) suggests that higher levels of joint-agency are associated with lower levels of self-agency. In these studies, pairs of participants co-ordinate their actions together to produce a series of tones.

After each trial participants are asked to ‘‘[r]ate your feelings of control over the timing of the sequence” on a scale ranging from ‘‘shared control” to ‘‘independent control”. They observed increased shared control when participants had to co-ordinate their actions with each other by alternating, compared to sequentially, making key presses (Bolt et al., 2016), and when they were better able to co-ordinate their actions (Bolt & Loehr, 2017). Importantly the scale used suggests that, in these situations, this increased sense of joint agency corresponded to a decrease feeling of “independent control”; i.e. sense of self-agency.

Whilst these studies have shown how different factors may affect our experience of agency when acting with others, they cannot tell us how the phenomenology of joint action, corresponds to that when acting alone. A number of studies have compared these two conditions using similar self-report methods. Typically, these studies have shown a reduction in agency when acting with others compared to oneself (Dewey et al., 2014; van der Wel et al., 2012)

For example, van der Wel., et al (2012) conducted a study comparing the phenomenology of acting alone, or with another. The task consisted of moving a pole back and forth between two target locations either by oneself, or with a co-participant. After each trial they were asked to rate how in control they felt they were over the movement of the pole. They observed increased judgments when acting alone, compared to with another. Also, the researchers

observed that, when first completing the task with another, participants reported increased control when subsequently acting independently. The authors have suggested that participants may have used their ratings of control in the joint task as a baseline, against which to measure their ratings of control when acting alone. This illustrates one issue with methods commonly used to assess the phenomenology of joint action; judgments are affected by their prior estimates and are made in relation to them.

Such demand effects may be avoided by using implicit measures. Although not commonly used in joint action research, they have been widely used when studying self-agency (Moore & Obhi, 2012). These methods allow for one's experience of agency over an event to be measured, without requiring participants to consciously recall their experience of the event. Using an implicit measure of self-agency would allow us to determine whether our experience of control when acting alone can offer any insight into our experience when acting with others, without the demand effects associated with explicit measures. By comparing an implicit measure of self-agency, with explicit judgments of control during joint action, we can better understand how the experience of acting alone may relate to our experience when acting with others. Specifically, do high trait levels of self-agency correspond to high levels of agency when working with others, or, do those who have a clearly defined sense of self-agency find it harder to form a joint

agentic identity with others? A positive correlation would suggest the former, a negative the latter.

In the present exploratory experiment, we consider the relationship between our sense of agency when acting alone, compared to with others, but from a different angle than previous research. Here we investigate whether one's putative trait level of self-agency, as measured implicitly using intentional binding, is related to the degree of joint agency one experiences when performing a separate joint action task. In particular, we are interested in whether higher-levels of trait self-agency impede the development of joint-agentic experiences. If this proves to be the case then it would help shed light on the nature of these two aspects of agentic experience as well as the relationship between them.

We have three hypotheses. Firstly, we expect to replicate the intentional binding effect, with smaller interval estimates being observed for volitional, compared to non-volitional actions (Haggard et al., 2002). Secondly we expect to replicate the difference in control ratings between joint and individual action observed in previous research using a similar design, with control ratings being higher when acting independently, compared to with another (van der Wel et al., 2012). Finally, our key hypothesis is that there will be a negative correlation between intentional binding and control ratings when acting with others, indicating that high trait levels of self-agency are associated with a reduced sense of agency when acting with others.

4.2. Method

Participants

Visitors to London Science Museum were asked to participate in a series of experiments. A total of 1083 visitors participated. For participants to be included in the current study, participants completing the joint action task together both had to have completed the intentional binding task as well. They had to be above the age of 12, and to have English as their first language. In line with these inclusion criteria, data from 40 participants were used for analysis in the current study. The age range was 12 to 61 years (M = 25.62, SD = 11.1). 20 participants were female, 20 were male.

Apparatus and materials

The current study involves correlating the results of participants from two separate experimental designs. Each experiment will thus be discussed separately.

Intentional Binding

The experimental script was written in MatLab (2017a) and presented using a MacBook Pro (Early 2015), MacBook Air (Early 2015), or Toshiba (Satellite L500-D). The same external keyboard was used for participant responses, regardless of computer. Headphones (Seinheisser HD 206) were used to present outcome tones.

Joint Haptic task

A rectangular box with ropes extending at either of the short ends, and a pole protruding from the centre of the top panel was used to complete the haptic task. Movement of either rope would cause the angle of the pole, relative to the pulled rope, to increase. The box was based on designs provided by Norbert Hermesdorf and Robrecht van der Wel at Radboud University. The experimental script was written in C++. Speakers (Logitech Z200) were used to present a pacing metronome presented at the start of each trial. Force and angle data were recorded via a computer connected to the haptic box. Each participant's self-report of performance was recorded on a tablet (Amazon Fire 5). A goniometer was used to measure the change in the angle of the pole, two load cells were used to measure force applied to each rope.

Procedure

Intentional Binding

Intentional binding is a commonly used implicit measure of the sense of agency. The measure involves comparing participants' perception of the temporal relationship between one's action and its outcome. The original study observed that when actions are produced volitionally, compared to non-volitionally, the time of the action and its outcome are perceived as occurring closer together; i.e. they are *intentionally bound* (Haggard et al., 2002). The

current study implements an interval estimation approach to the intentional binding task, in which participants estimate the interval between action and outcome events, rather than separately reporting the time of each. Our method is described in detail below.

Once informed consent had been taken participants were sat in front of a computer and put on a pair of headphones. Participants firstly completed one practice trial, in which they were asked to depress a keyboard key, at a time of their choosing with their right index finger. This would cause a subsequent tone after 1000ms. Participants were informed of the length of the interval in the practice trial and that the length of the interval in the experimental trials will never be longer than 1 second. Participants then completed the two experimental blocks; volitional and non-volitional (order alternated based on subject number). In the volitional block participants depressed the key volitionally (as in the practice trial), in the non-volitional block the experimenter depressed the participants finger onto the key. In each trial, the action-tone interval was either 300, 500, or 700ms; two of each interval were presented pseudo randomly within each trial block. In each trial, once the tone had occurred, participants used the keyboard in order to enter their estimate of the action-tone interval. Each experimental block consisted of 9 trials. Once both experimental blocks were completed they were debriefed and free to leave.

Joint haptic task

We assessed changes in agency when acting independently or co-operatively by replicating the joint haptic task previously used by van der Wel et al., (2012). Our method is described in detail below.

Participants completed a joint and an individual experimental block, both consisting of 5 trials. The order of experimental blocks was counterbalanced. In the individual experimental block they completed each trial by themselves, controlling the cord on the left side of the apparatus with their left hand, and the cord on the right side with their right hand. In the joint experimental block, they completed each trial jointly with another participant. The participants sat either side of the apparatus, approximately 50 cm from each other, and controlled the cord on their side of the box with the appropriate hand (i.e. left hand on left side, right hand for right side). At the beginning of the experiment participants were informed they were to move the pole back and forth between two targets using the cords. Target areas were indicated by 0.5cm coloured regions 2cm either side of the pole when vertical. They were given one minute before the experimental trials began in order to familiarise themselves with the task and the co-participant. Participants were not allowed to speak to each other during the experiment.

Experimental trials began with the pole resting on the left side of the box and they were instructed to start moving the pole after hearing a sequence of eight isochronous tones, which indicated the tempo at which participants

were required to move the pole at. The sounds consisted of a series of 100ms long 700 Hz and 850 Hz tones, alternating back and forth four times, occurring at an interval of 546ms. Participants were instructed to listen to these tones and to begin moving the pole back and forth, at the same pace, after the final tone was heard. Once the goniometer had indicated that a sequence of fifteen oscillations had been completed a final 700Hz tone was heard, indicating the end of the trial. Once each trial had been completed participants used tablets in order to indicate how much control they felt they had over the movement of the pole, on a scale from 0 (no control) to 100 (full control). Participants were not able to see their answer on previous trials or their co-participants answers.

Data Analysis

Intentional binding

Each participant's interval estimates in each condition were averaged to create a single intentional binding score for volitional and non-volitional conditions.

Joint Haptic Task

Performance

Before analysis of their task performance, pole kinematics were filtered using a 20Hz Butterworth filter in order to remove noise. Our

minimum threshold angle for a direction reversal point was set to 20° so that small corrective movements were not counted. We then calculated the absolute deviation from the reversal angle and the instructed angle in order to calculate the mean end point error (MEE). The length of the movement period was calculated by determining the time between each MEE.

In order to create a single value that accounted for both spatial and temporal aspects of the task, a single performance score was computed from these values. This was achieved by normalising MEE and movement period scores for each participant, condition, and trial. MEE were normalised against the grand mean of all the data, such that scores below 1 indicated better performance, and scores above 1 indicated worst performance. Movement period was computed by taking the mean movement period for each trial. We then normalised against the absolute difference between the produced and instructed movement period, such that perfect performance corresponded to a normalised movement period of 1. We then summed both normalised MEE and movement period scores for each trial and condition. The lower the resulting values the better the performance. This value will be referred to as the Combined Error Score (CES).

Force

Within both conditions the mean force exerted on both ropes on each trial was computed. For the individual condition, the average force applied

across both ropes was taken. For the joint condition the mean force applied to the rope the participant was holding was taken.

4.3. Results

Intentional binding

A paired sample t-test did not find a significant difference between volitional (M = 297.504, SD = 133.351) and non-volitional (M = 324.8, SD = 162.123) conditions (t = 1.454, p = .154). This does not support our initial hypothesis.

Joint Haptic task – self reports of agency

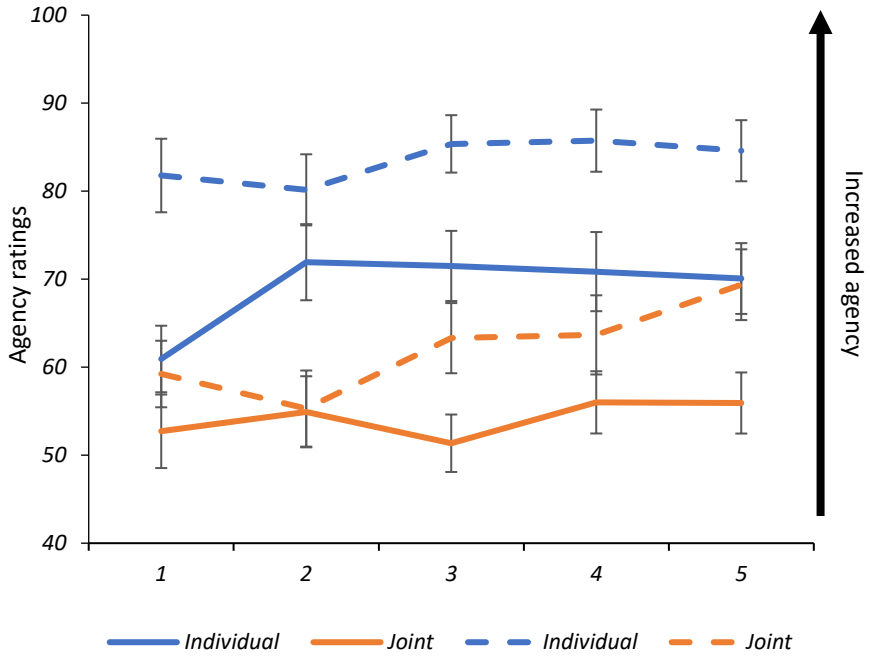
A 2 (Task order: Individual first; Social first) X 2 (Condition: Individual; Social) X 5 (Trial:1,2,3,4,5) repeated measures Analysis of Variance (ANOVA) was conducted. Trial was not significant ($F_{(4,35)} = 1.449$, p =.238, η_p^2 = .139). A main effect of task order was observed ($F_{(1,39)} = 7.843$, $p < .01$, η_p^2 = .167), with agency ratings being higher when first completing the social (M = 72.848, SD = 11.267), compared to individual (M = 61.624, SD = 13.806), trial block. Post-Hoc between subject one-way ANOVA's were conducted on control ratings in the individual and joint task, with task order as the between subject factor. A significant effect of task order was observed for the individual task, with those who had completed the joint, rather than individual, task first having higher rating of control ($F_{(1,39)}$ =

5.816, p <.05, η_p^2 = .133) . No effect of task order was observed for the joint task ($F_{(1,39)}$ = 1.495, p =.229, η_p^2 = .038).

A main effect of condition was also observed ($F_{(1,39)}$ = 20.063, p <.001, η_p^2 = .34) with agency ratings being higher in the individual (M = 78.585, SD = 17.94) compared to social (M = 59.444, SD = 18) conditions. There were no significant interaction effects. The results agree with our initial hypotheses. The results can be seen in Figure 10.

Figure 10

Agency ratings in joint haptic task across trials



Note. Solid lines represent participants who completed the individual trial block first, dotted lines represent those participants who completed the social trail block first. Error bars represent standard error.

t-test of relationship to objective control in joint condition.

A t-test was conducted assessing participants reported judgments of control in the joint condition against their objective level of control over the task (i.e. 50%). This indicated that self-reports of control were significantly higher than their objective level of control ($t = 3.405$, $p < .01$).

Correlation between intentional binding and self-reports of agency in haptic task

In order to provide a single composite intentional binding value to be correlated with self-reported agency on the joint haptic task, each participant's mean binding score in the volitional condition was deducted from their score in the non-volitional condition. Thus, larger values would indicate increased intentional binding.

The correlation between the composite binding score and self-reports of agency in the individual joint haptic condition was not significant ($r_{(40)} = -.307$, $p = .054$). The correlation between the composite binding score and self-reports of agency in the *social* joint haptic condition, indicating that increased binding corresponded to reduced self-reports of agency in a social context ($r_{(40)} = -.326$, $p < .05$, see Figure 11).

Supplementary analyses

We also conducted further exploratory analyses to examine specific aspects of physical performance on the joint haptic task and their relation to agency.

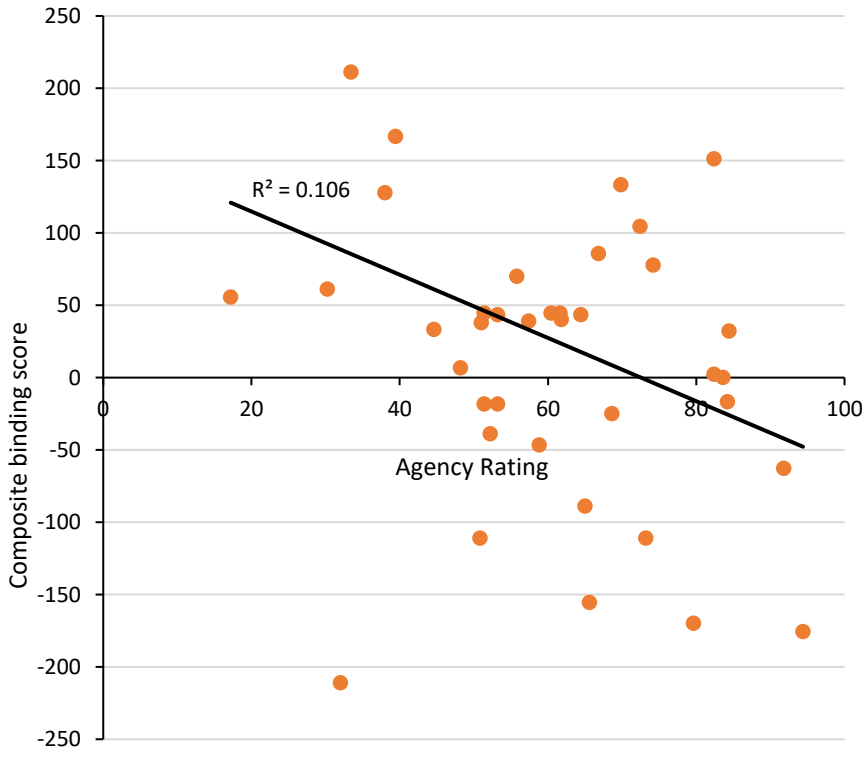
Performance on the joint haptic task

In order to evaluate participant performance, we conducted a 2 (Condition: Individual; Joint) x 5 (Trial: 1-5) ANOVA with condition order (Individual first; Joint first) as a between subject factor. These results can be seen in Figure 12.

A main effect of trial was observed ($F_{(4,35)} = 2.776$, $p < .05$, $\eta_p^2 = .241$), such that performance improved with trial number. There was also a significant effect of Condition ($F_{(1,38)} = 21.453$, $p < .001$, $\eta_p^2 = .361$), with participants performing better on the individual (M = 1.938, SE = .041) , compared to joint (M = 2.212, SE = .064) condition. The main effect of condition order was not significant ($F_{(1,38)} = 2.341$, $p = .134$, $\eta_p^2 = .058$), and there were no significant interaction effects.

Figure 11

Scatterplot of correlation between agency ratings in the joint condition of the haptic task and Intentional binding



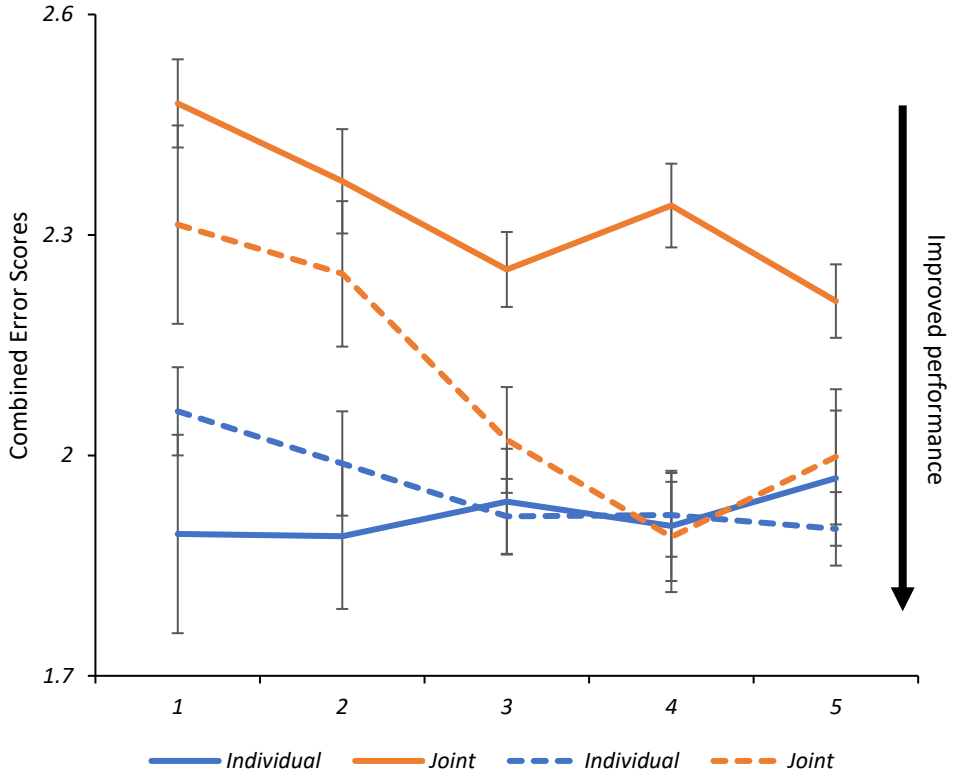
Note. Larger composite binding scores indicate increased intentional binding. Solid lines represent linear trend.

Relation between performance and agency

Mean Self-reports of agency and CES scores across all trials, for each condition, were then subjected to a bivariate correlation for both task orders. For the joint condition, when completed after the individual condition, a significant positive relationship was observed between CES and self-reports of agency (r = .797, p<.01). No other correlations were observed.

Figure 12

Mean Combined Error Scores (CES) across trials



Note. Solid lines represent participants who completed the individual condition first, dotted lines represent those participants who completed the joint condition first. Lower scores indicate better performance. Error bars represent standard error.

Relation between force and agency

Mean force measurements were correlated against agency rating for both conditions and conditions orders. No significant correlations were observed.

4.4. Discussion

The current study aimed to assess whether intentional binding correlates with explicit judgments of agency taken whilst completing a haptic task, either alone, or with another person. In regard to the haptic task, we replicated the over-estimation of control ratings in the joint action task. A significant difference between the active and passive conditions of the intentional binding task was not observed. Composite binding scores were shown to negatively correlate with explicit reports of agency in the joint condition of the haptic task, supporting our key hypothesis. Below a discussion of the implication of these results shall be given, and limitations of the current study outlined.

Firstly, our results from the haptic task replicated the previously reported difference in judgments of control when acting alone compared to with another. Specifically, participants reported higher ratings of control in the individual condition compared to the joint condition. It was also observed that self-reports in the joint condition were higher than their objective level

of control (i.e. greater than 50). This suggest that, when acting with another, we overestimate our unique contribution to the joint action (van der Wel et al., 2012). This may suggest that, when acting with others, the reduced sense of self-agency experienced is counteracted by a sense of joint agency.

We also replicated the effect of task order on judgements of control, with judgments, in the individual condition, being higher when participants first completed the task with a co-participant. This adds further support for the notion that we use our estimates of control when acting with others as a baseline, against which to estimate our sense of agency when acting alone (van der Wel et al., 2012). It also implies that we may experience more control over our actions when first learning with others.

In regard to our primary aim – assessing whether ones trait level of self-agency is correlated with the sense of agency during joint action – we observed a negative correlation. To elaborate, our results indicate that those who implicitly feel a large difference in their sense of agency when acting volitionally, compared to having their actions forced by another (i.e. the intentional binding task), report less agency when having to co-ordinate their actions with others. This suggests there could be a relationship between our sense of agency when acting alone compared to with others, with those who have a strongly defined sense of self-agency feeling a larger reduction in their sense of agency when having to co-operate with others in an egalitarian manner.

Some support for this idea may be offered when considering the observed correlation between performance and agency ratings in the social condition of the haptic task. Self-reports negatively correlated with performance in the social condition when it was completed second. When completing such egalitarian co-operative actions it has been suggested that we can experience a blending of self and other (McNeill, 1995). Increased cohesion between co-agents has also been shown to increase participants experience of joint, compared to individual, agency (Bolt et al., 2016; Bolt & Loehr, 2017). Improved performance can be considered as indicative of increased self-other blending, which can reduce judgments of self-agency. Thus, as they get better able to complete the task, by working effectively together, they may have felt a reduced sense of self, and increased sense of joint, agency, resulting in the observed decreased agency scores. This suggests that changes in the participants' experiences of control during the joint task were driven by changes in joint agency, which we suggest is already reduced in those with high trait levels of self-agency. Nonetheless, such an interpretation does not explain why no correlation was observed when completing the social task first.

An alternative explanation is that the results correspond to the extent to which self-agency is experienced when interacting with others. Pacherie (2012) has suggested that, when actors are easily able to distinguish their actions from their co-actors, they are likely to experience both self- and joint-

agency. It may be that those with high trait levels of self-agency feel a larger reduction in self-agency when having to interact with other people, irrespective of if that interaction is volitional (joint condition of joint haptic task) or non-volitional (non-volitional condition of intentional binding task). Both of these theories – high trait self- agency corresponds to decreased joint-agency or decreased self-agency when engaged in joint action - offer a plausible explanation, however further research, which separately assesses judgements of joint and self-agency, would be needed to determine which is correct.

Such further research would also allow for a number of other limitations with the current study to be addressed. Firstly, we did not observe a significant difference between volitional and non-volitional conditions in the intentional binding task. This is most likely due to the low number of trials conducted in the current study, a requirement for the public engagement setting of the study. Thus whilst previous literature has consistently found the intentional binding effect (Haggard et al., 2002; Moore & Haggard, 2008; Moore & Obhi, 2012; Sidarus et al., 2013), the current study should be replicated using a more robust binding paradigm in order to strengthen our interpretation of the reported findings. Such a replication would also benefit from being conducted in a laboratory setting, which would reduce the high attrition rate reported and create a more controlled environment for testing.

To conclude the current study observed a negative relationship between trait levels of self-agency, as measured by intentional binding, and the sense of agency during joint action. We have suggested this may be due to those with high trait levels of self-agency being less able to engage in a joint agentic identity. However, this interpretation is speculative and further research, which measures self and joint agency separately, would be needed in order to support or negate our interpretation of the current findings.

5. Flow and the sense of agency during joint action

5.1. Introduction

Our ability to complete co-ordinated joint actions has been key to our success as a species. Such actions are commonly occurring, whether it be carrying a couch up some stairs, dancing with another, or effectively co-operating during team sports. They involve the use of numerous cognitive mechanisms and can produce unique, often highly rewarding, phenomenological experiences. Our understanding of this phenomenology is now rapidly improving, with technological advances making it easier for researchers to assess how changes in our interactions can affect our subjective experience.

For example, during such actions our sense of agency may change, such that we incorporate the actions of others into our agentic experience. This merging of self and other has been referred to as the sense of joint agency (Pacherie, 2012). Recent research has attempted to understand the key factors that underly joint agency, as well as what causes individuals to feel joint, rather than individual agency when acting with others. For example, Bolt and Loehr (2017) found that participants' agentic experiences can be modulated by the predictability of a co-agents actions, whilst others have shown being first or second to act has a large effect on the sense of agency (Dewey & Carr, 2013; Pfister et al., 2014). Another key factor for the emergence of joint

agency is that actions are egalitarian, with agents viewing each other as having an equal impact on the joint goal (Le Bars et al., 2020).

In some egalitarian settings, such as dance, individuals may even feel a "blurring of self and other awareness and the heightening of fellow feeling" (McNeill, 1995). Such a state could also indicate participants were experiencing group flow, which occurs when a group is performing at its peak, acting as a single unit, with each action appearing to come naturally, and members feeling they can anticipate their fellow performers actions (Sawyer, 2017). Group flow is based upon the concepts of flow developed by Csikszentmihalyi (1991), which have been expanded to consider group actions. Sawyer (2017) has suggested there are ten characteristics required for group flow to emerge. There must be (1) a shared goal between co-agents; (2) 'deep listening', in which co-agents do not have to plan their actions ahead, and instead respond naturally (i.e. without prior thought); (3) complete concentration such that they become almost unaware of things external to the task; (4) feel in control of their actions, such that they have autonomy over their movements; (5) a blending of egos such that each person's actions become merged with that of the group; (6) equal participation from co-agents, such that all participants feel their actions matter equally towards the shared goal; (7) agents must have a sense of rapport with all other co-agents such that they share a common set of un-spoken rules; (8) participants must be able to communicate with each other; (9) be able to build upon their actions in

order to move the interaction forward; (10) and the potential to fail at the task. Many of these characteristics also appear important for the sense of agency – e.g. having autonomy of movement – and the sense of joint agency – e.g. equal participation - yet little research has assessed the relationship between them.

This could be due to differences in the way agency and flow are typically studied. Group flow is often assessed using naturalistic methods, with a mixture of both quantitative and qualitative reports, often involving a creative task (for review see: Pels et al., 2018). When empirical measures are taken they a in the form of surveys, with numerous different measures created (Jackson & Eklund, 2002; Jackson & Marsh, 1996; Magyaródi & Oláh, 2015; Salanova et al., 2014; Zumeta et al., 2016). Of these, Jackson and Eklund's (2002) Flow State Scale–2 has become the most widely used. The survey consists of 36 items, each of which is answered on a 5-point Likert scale from 1: "Strongly Disagree" to 5: "Strongly Agree". However, the survey was originally designed in order to study individual flow, limiting its ability to inform us about group flow due to the self-centred nature of the questions. Others have created surveys specifically asking about group flow (Magyaródi & Oláh, 2015), though these have not been tested as extensively.

In contrast, the sense of agency during joint action is predominantly studied using lab based, highly structured tasks. Often participants will be instructed to make alternating or co-ordinated actions with a co-participant,

with either implicit (Obhi & Hall, 2011a; Pfister et al., 2014; Sahaï et al., 2019) or explicit measures of agency taken. (Bolt et al., 2016; Bolt & Loehr, 2017; Dewey & Carr, 2013; Le Bars et al., 2020). Whilst these studies have improved our understanding of the sense of agency during joint action, they differ greatly from the more naturalistic settings of group flow research.

Fortunately, Nalepka et al., (2017) recently created a paradigm which may allow for both group flow and agency to be measured. The virtual herding task involves two participants working together in order to herd a group of 'virtual sheep' into the containment area in the centre of a virtual game-space. Participants each use a handheld puck to control a 'sheep-dog' within the game-space. The sheep are programmed to flee from the sheep-dog, allowing participants to corral the sheep into the containment space. Typically, participants begin the study using a sub-optimal strategy, in which the participants act independently, but over the course of the experiment many participants organically learn to work together in order to optimally complete the task; using their sheep-dogs to create a spatio-temporal wall between the sheep and the edge of the containment area.

The current study aimed to assess the relationship between agency and flow during the virtual herding task by including self-report measures of both cognitive mechanisms. A number of predictions were made regarding how the interaction between participants, as well as their performance, may affect the sense of agency and group flow. First, we predicted that sense of agency

would positively correlate with task performance. Our second hypothesis was that agentic state would be correlated with movement behaviour, such that increased joint agency would be observed when participants movements were more indicative of a coupled oscillatory movement strategy. Third, group flow will be affected by the movement behaviour of participants, such that increased group flow was reported when movements were more indicative of a coupled oscillatory movement strategy. Fourth, we predicted that there would be a positive correlation between the sense of agency and group flow. And finally, our key hypothesis was that group flow would be associated with increased experiences of joint, compared to self, agency.

5.2. Method

Participants

54 participants were recruited from the Goldsmiths community (Age: 25.6 (7.23)) consisting of 27 pairs of subjects (MM = 1; MF = 10; FF =16).

Apparatus and materials

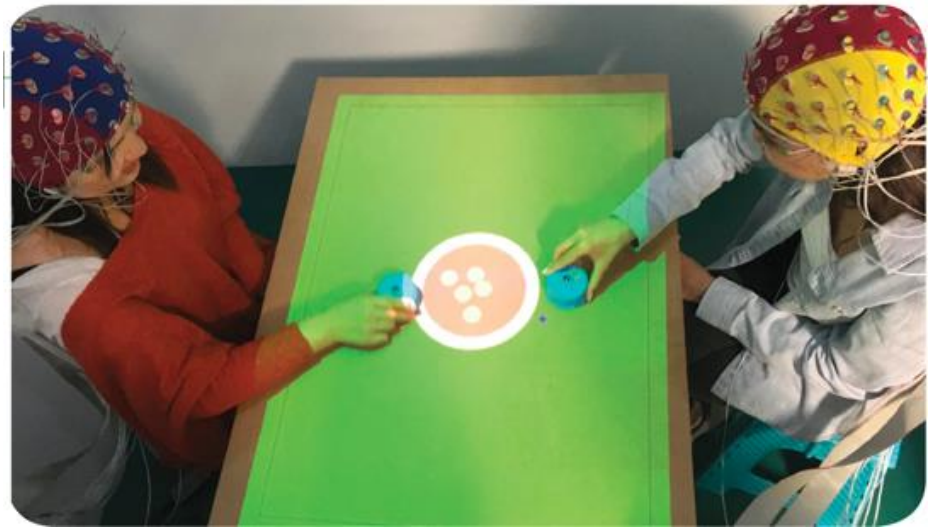
Virtual herding task

The experimental 'virtual herding' task was written in C++. A projector was used to present the virtual game-space onto a table (see figure 13). A participant sat at either end of the table, holding an infrared equipped 'puck' that could be moved around the table. An infrared camera was used to

record the position of the pucks and display their position into the virtual game-space. The game-space consisted of a green background with a black border around its perimeter. In the centre of the games space was a red circle with a white boarder. Five grey markers (‘sheep’) were projected onto the centre circle of the game-space at the beginning of each round. The sheep began moving randomly around the game-space using Brownian motion. The sheep were programmed to retreat from the pucks (‘sheep dogs’) with their velocity proportional to their distance from the sheep dogs. Participants were required to use this repulsion of the sheep from the sheep dogs in order to contain the sheep within the central red circle of the game-space. Each trial lasted a maximum of two minutes. If all five sheep were entirely contained within the red circle for 70% of the last 45 seconds, the trial would end and the message ‘won’ would be projected onto the table. If any of the five sheep

Figure 13

graphic of virtual herding task set-up



touched the black boarder than the trial would end, and the message ‘lost’ would be projected onto the table along with the percentage of time the sheep were contained in the last 45 seconds of the trial. If the sheep had not been contained by the end of the two-minutes the trial was considered lost and the message ‘lost’ would be projected onto the table along with the percentage of time the sheep were contained in the last 45 seconds of the trial.

In a control condition, participants completed passive, ‘playback’, trials, in which subjects completed the same movements as in experimental trials, but with their actions instructed, rather than freely chosen. In playback trials participants viewed a recording of the previous trial, which was projected onto the table, with the sheep removed. Participants were required to use their puck in order to simply follow the projected position of their sheep dog in the game-space. This allowed us to measure the experience of completing the same motor action without the need for interaction with their co-participant, or decision making from the participant. Task difficulty was not modulated throughout the experiment.

Surveys

The current study was part of a larger project, which involved the collection of neuroimaging and self-report data. The current study focuses on a sub-set of these data; responses to the first and last trials in the active condition and the passive playback condition. Participants completed a series of self-report

measures, which consisted of four sections; three surveys and some single point questions. The first consisted of the short version of the Flow State Scale - 2 (Jackson & Eklund, 2002; See appendix 2). The second consisted of the, 28-question, Flow Synchronisation Scale (Magyaródi & Oláh, 2015; See appendix 3), which assessed 5 subcomponents of group flow: synchronisation and effective cooperation with group members; experience of engagement and concentration; individual motivation and learning; partner motivation and learning; coordination with partner during activity. The third section consisted of the 13-question Sense of Agency Scale, the scale consisted of two sub-components: Sense of Positive Agency; Sense of Negative Agency (Tapal et al., 2017; See appendix 4). The final section consisted of 4 questions which measured participants' experiences of control and harmony: one question concerning their experience of agency, one concerning their agentic state, one concerning their experience of ownership, and one concerning their experience of flow (See appendix 5).

These measures were taken on the first and last active trials of the experiment, as well as their related playback trials.

Procedure

Two participants were required to co-operate in order to complete the 'virtual herding' task. Once consent had been taken from both participants, they were asked to enter the test room with one participant sitting at either

side of the table, onto which the virtual herding task would be presented (See figure 13). Each participant was given a puck in order to complete the task. Participants were informed not to talk to each other during the game. Participants were instructed that they should use their puck in order to contain the white dots ('sheep') in the central red circle of the screen for as long as possible; i.e. use their 'sheep dog' to 'herd the sheep' into the central red circle.

Participants completed one practice trial, with a reduced Brownian rate in order to familiarise themselves with the task and rules (a reduced Brownian rate decrease the frequency with which the sheep changed direction, making them easier to catch). After the practice trial participants completed their first regular trial (i.e. attempted to herd the sheep), which was then followed by a playback trial. Testing continued for 90-minutes, with a playback trial completed after the first trial, after 30, 60 and 90 minutes (i.e. their final trial was a playback trial).

Performance analysis

Previous research using the virtual herding paradigm has indicated two behavioural strategies used to complete the game (Nalepka et al., 2017). Commonly, participants first try to herd the sheep by using their puck to push any wayward sheep back into the central red circle. This search and recover strategy requires little co-operation between co-participants and is not the

optimum method as participants can only recover a single sheep at a time, by which point the others have scattered. Over time, participants often moved to a more effective strategy, in which they work together in order to create a spatio-temporal wall around the red circle with their pucks, thus trapping the 'sheep' inside. Using this coupled oscillatory containment strategy involves a heightened level of concentration and co-ordination between both participants as they must synchronize their actions. The distinction between these two behavioural strategies can be seen in figure 14.

In order to assess participants' movement behaviour, the participants' movements within the game-space were recorded and the extent to which participants were engaged in search and recover or coupled oscillatory containment task strategy was computed. Coupled oscillatory containment behaviour was associated with oscillations in the polar angle of movements of both participants between 0.5 and 2.0 Hz, and a frequency power spectra of the polar angle above 0.5Hz. The dominant movement behaviour in each trial was determined by measuring the polar-angle-movement time series for each participant i in each participant pair k (k = 1, 2, . . . 54) to identify the strongest frequency component, $\omega_{frequency,i,k}$, under 2.0 Hz—that is, the frequency component with the greatest "peak" power in this frequency range; the pwelch function in MATLAB (The MathWorks, Natick, MA) was employed using a 50%-overlapped window of 512 samples. This frequency component, and its power, $\omega_{power,i,k}$, were then used to determine the

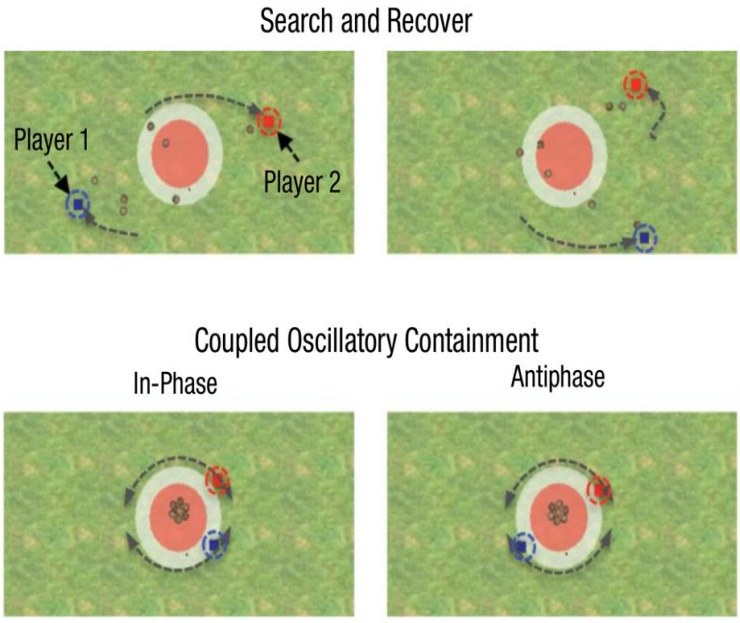
dominant behaviour , ωi,k , adopted by each participant for each trial, as follows:

$$\phi i, k = \frac{\omega \text{frequency, i, k} - .5}{|\omega frequency, i, k - .5|}\ \omega power, i, k'$$

with the 0.5-Hz classification boundary determined empirically by inspecting the entire data set. . The larger the resulting ϕi value, the more participants were engaged in coupled oscillatory containment behaviour. Finally, the movement behaviour each pair, in each trial was determined by averaging the ϕi computed for each participant in a pair.

Figure 14

Illustration of task strategies



5.3. Results

Trial-Condition Repeated Measures Analysis of Variance

A 2 (trial: first; last) x 2 (condition: active; passive) analysis of variance was conducted on subjects' responses to all our self-report measures.

Harmony

For the single point survey question 'How strongly do you feel you were working in harmony with the other player?'. 6 subjects were removed due to missing data. A highly significant effect of trial was observed ($F_{(1,48)}$ = 26.016, $p < .001$), with subjects reporting increased harmony in the final trial. A highly significant effect of condition was observed ($F_{(1,48)}$ = 12.628, $p < .001$), with subjects reporting more harmony in the active, compared to passive condition. No interaction between variables was observed.

Control

For the single point survey question 'How strongly do you experience being in control over the movement of the sheep?'. 6 subjects were removed due to missing data. A highly significant effect of trial was observed ($F_{(1,48)}$ = 29.282, $p < .001$), with subjects reporting increased harmony in the final trial. A highly significant effect of condition was observed ($F_{(1,48)}$ = 16.71, $p < .001$), with subjects reporting more harmony in the active, compared to passive condition. No interaction between variables was observed.

Agentic state

For the single point survey question 'Rate your feelings of control over the herding of the sheep on a scale from 01 (shared control) to 99 (independent control)'. 16 subjects were removed due to missing data. A significant effect of trial was observed ($F_{(1,38)} = 6.415$, $p < .05$), with subjects reporting increased harmony in the final trial. No effect of condition was observed ($F_{(1,38)} = .204$, $p = .654$). No interaction between variables was observed.

Flow Synchronisation Scale

Preliminary analyses indicated a significant positive correlation between all 5 subcomponents of the Flow Synchronisation Scale (see table 4). Therefore, all components were combined for the current analyses. 9 subjects were removed due to missing data. A highly significant effect of trial was observed ($F_{(1,45)} = 35.778$, $p < .001$), with subjects reporting increased harmony in the final trial. A highly significant effect of condition was observed ($F_{(1,45)} = 26.362$, $p < .001$), with subjects reporting more harmony in the active, compared to passive condition. No interaction between variables was observed.

Table 4

Correlation of factors from flow synchronisation scale

Variables	1	2	3	4	5
1. Synchronise	__				
2. Concentrate	.51**	__			
3. Self motivation	.86**	.69**	__		
4. Partner motivation	.71**	.40**	.76**	__	
5. Coordination	.79**	.42**	.76**	.78**	__

**. Correlation is significant at the 0.01 level (2-tailed).

Flow State Scale

For the short Flow State Scale – 2, 7 subjects were removed due to missing data. A highly significant effect of trial was observed ($F_{(47)} = 26.836$, $p < .001$), with subjects reporting increased harmony in the final trial. No effect of condition was observed ($F_{(1,47)} = 1.405$, $p = .242$). A significant interaction was observed between trial and condition ($F_{(1,47)} = 7.328$, $p < .01$) with a double dissociation being reported between factors, such that for the first trial, higher scores were reported for the passive condition, whilst for the last trial, higher scores were reported for the active condition.

Sense of Agency Scale

The sense of agency scale consists of two sub-components – sense of positive agency; sense of negative agency. These two components did not

correlate with each other and were analysed separately. 7 subjects were removed due to missing data.

For the sense of positive agency, a significant effect of trial was observed ($F_{(1,47)} = 6.694$, $p < .05$), with subjects reporting increased positive agency in the final trial. A significant effect of condition was observed ($F_{(1,47)} = 6.701$, $p < .05$), with subjects reporting more positive in the active, compared to passive condition. No interaction between variables was observed.

For the sense of negative agency, no effect of trial was observed ($F_{(1,47)} = 1.065$, $p = .308$). A significant effect of condition was observed ($F_{(1,47)} = 8.485$, $p < .05$), with subjects reporting more negative agency in the passive, compared to active condition. No interaction between variables was observed.

Correlation of task performance, movement behaviour and self-report measures

Mean differences were computed for performance, movement, and self-report data from the first and last active trials, such that positive values indicated higher responses on the last trial. This created a single value for each measure which would represent how it had changed over the study. The resulting values were then analysed within a bivariate correlation (see table 5). In order to assess our specific hypotheses regarding the specific influence

of performance and movement behaviour on agency and flow, groups of partial correlations were also created. The first looking at the effect of performance on agency when controlling for movement behaviour (see Table 6), the second looking at the effect of movement behaviour on flow (see Table 7), when controlling for performance.

Some observed correlations of particular importance to the current study are: the significant positive correlation between task performance and participants movement ($r = .44$, $p < .001$); the significant correlation between our single point measure of agency and task performance ($r = .49$, $p < .001$); the lack of a significant correlation between agentic state and movement behaviour ($r = -.12$, $p = .409$), or any of our flow scales; the significant correlation between our single point measure of agency and our single measure of flow ($r = .60$, $p < .001$), the flow state scale ($r = .47$, $p < .001$) and the flow synchronisation scale ($r = .67$, $p < .001$).

Table 5

Correlation of difference between first and last trials for self-report and task variables

Variable	*n*	M	SD	1	2	3	4	5	6	7	8	9	10
1 Task performance	54	26.24	27.64	__									
2. Participant movement	54	.17	.23	.44**	__								
3. Combined movement[a]	54	.17	.23	.53**	.82**	__							
4. Harmony	53	.89	1.72	.60**	.17	.21	__						
5. Control	53	1.38	1.72	.49**	.33	.28	.60**	__					
6. Agentic state	47	-11.30	32.89	.00	-.12	-.01	-.17	.08	__				
7. Flow State Scale	52	.46	.58	.62**	.35	.38*	.45**	.47**	-.10	__			
8. Flow Synchronisation Scale	53	.54	.80	.60**	.21	.25	.67**	.46**	-.20	.57**	__		
9. Sense of Positive Agency	53	.09	.86	.11	.07	.16	.24	.31*	.26	.06	.06	__	
10. Sense of Negative Agency	52	-.06	.71	-.28	-.10	-.17	-.04	-.18	-.03	-.30*	-.09	-.20	__

Note. Significance levels altered for multiple comparisons

[a] Represents averaged movement behaviour of both participants

*. Correlation is significant at the 0.005 level (2-tailed)

**. Correlation is significant at the 0.001 level (2-tailed)

Table 6 *Partial correlations of movement behaviours against flow, accounting for effect of performance.*

Variable	*n*	1	2	3	4	5
1 Task performance	54	__				
2. Control	53	.32	__			
3. Agentic state	47	.1	.15	__		
4. Sense of Positive Agency	52	-.05	.18	.04	__	
5. Sense of Negative Agency	52	-.28	-.22	-.05	.04	__

Table *7* *Partial correlations of flow against movement behaviour, accounting for effect of performance*

Variable	*n*	1	2	3	4
1. Participant movement	54	__			
2. Harmony	53	-.16	__		
3. Flow State Scale	47	.09	.12	__	
4. Flow Synchronisation Scale	52	-.1	.48**	.31	__

5.4. Discussion

Overview

In the current study, a complex joint action was completed whilst measures of the sense of agency and group flow were taken. Our aim was to assess how our subjective experience of joint action changes as people learn to co-operate more effectively. Of specific interest was the relationship between group flow and the sense of agency.

As with previous research, using a similar design (Nalepka et al., 2017), we found that participants' performance on the task positively correlated with pairs utilising a coupled oscillatory containment, rather than search and recover, task strategy. Coupled oscillatory containment behaviour involved participants moving synchronously, or asynchronously around the central containment area of the game-space and represented the optimum strategy. The correlation illustrates that when participants were able to more effectively co-ordinate their actions together, they performed better at the task.

A number of predictions were made regarding how task performance and task strategy would correspond to our self-report measures of agency and flow. First, we predicted that the sense of agency would be correlated with task performance. Our single point measure of agency supported this hypothesis (positively correlating with task performance). The negative component of the sense of agency scale (Tapal et al., 2017) also offered

support for this hypothesis (negatively correlating with task performance), though the positive component found no effect. Taking these findings into account, the experimental hypothesis was accepted.

Second, we predicted that participants' agentic state would be dependent on their movement behaviour, with more joint agency being experienced when a coupled oscillatory containment task strategy was used. Movement behaviour was not shown to correlate with their agentic state, thus the experimental hypothesis was rejected.

Third, we predicted that group flow would be positively correlated with the sense of agency. A strong positive correlation was observed between our single point measure of agency and all flow measures. In contrast, the sense of agency scale was not shown to correlate with any flow measures. Taken together, and due to the strength of the correlation with our single point measure, as well as concerns over the sense of agency scale (see below), our primary experimental hypothesis was accepted.

Fourth, we predicted that group flow would be dependent on the movement behaviour of participants. The flow synchronisation scale (Magyaródi & Oláh, 2015), and our single point measure of group flow, did not support this hypothesis, with no correlation with movement behaviour being observed. In contrast, the shortened flow state scale - 2 (Jackson & Eklund, 2002) supported the hypothesis, positively correlating with task

strategy. Nonetheless, due to the lack of consistency between measures, the experimental hypothesis was rejected.

Finally, our key hypothesis was that group flow would be associated with an increased experience of joint, rather than self, agency. Agentic state was not found to correlate with any of our flow measures. As such, the experimental hypothesis was rejected.

The observed findings will now be related to the sense of agency and group flow in more depth, limitations outlined, and future research suggested.

Sense of Agency

In regard to the sense of agency, a large difference in effects was observed between our single point measure, and the sense of agency scale (Tapal et al., 2017). Our single point measure, which asked specifically about subject's experience of control over the sheep, correlated with, task performance, movement behaviour, and all flow measures. In contrast, the single point measure only weakly correlated with the sense of agency (positive correlation with the scales positive component). The sense of agency scale also did not correlate with our flow measures. We suggest that the difference between measures is due to the nature of the sense of agency scale; which measures one's general, trait-level, perception of agency. Support for this can be seen in the lack of a consistent change between scores in the first and last trials, suggesting perception of agency over each trial may

have had little effect on the measure. As such, our single point measure was considered a more reliable indicator of participants perception of the task.

As mentioned above, the correlation with task performance was predicted, and is consistent with previous joint action research (van der Wel et al., 2012). Our findings add to this, illustrating the same effect in a more dynamic, less structured task. Specifically, the current study involved multiple moving targets, causing participants to constantly re-orientate their attention and actions. Whilst previous research has shown performance to affect the sense of agency, it has not been observed in such a dynamic joint action task, in which both the participants actions and the targets are freely moving.

We also observed a correlation between our single point measure and movement behaviour. Though not explicitly predicted, models of joint agency would indicate an increased feeling of joint agency when co-agents actions are more synchronous (Pacherie, 2012). Previous research has also shown joint agency to increase when participants are co-ordinating their actions more closely (Bolt et al., 2016). However, in contrast to this research, we observed quantitative, but not qualitative changes in the sense of agency as a result of movement behaviour. This quantitative change in the sense of agency was found to correlate more strongly with the participants individual movement behaviour rather than the averaged behaviour of both participants.

This indicates that participants perception of agency was more related to their own movements, rather than the combined behaviour of both agents.

The results of our analysis of variance test also suggest that individuals felt increased agency when making their action freely rather than when directed. Both the single point measure and sense of agency scale indicated larger responses in active, compared to passive, trials. This would fit with prior research observing a decreased sense of agency when our actions are directed (Caspar et al., 2016; Pfister et al., 2014). The current results add to this, by illustrating that even when replicating our own actions, rather than freely choosing them 'in-the-moment', our sense of agency is reduced.

Overall, the current results indicate that the sense of agency during joint action is predominantly affected by the performance of the group. However, the current results did not find agentic state to be dependent on performance, or movement behaviour. This would suggest that, whilst numerous factors were related to quantitative changes in the sense of agency, participants' agentic state (qualitative experience of agency) was reasonably fixed, only being affected by our familiarity in acting with another, rather than performance or behaviour on a trial-by-trial basis.

Group Flow

The primary aim of the current study was to assess how group flow is related to the sense of agency during joint action. The observed correlation

between our single point measure of the sense of agency and out measured of groups flow indicate that the sense of agency increased when in a group flow state. However, and in contrast to our main hypothesis, group flow was not shown to correlate with any change in agentic state. This is surprising considering the strong similarity between many key characteristics of group flow and joint agency. For example, group flow is said to require 'a common set of unspoken rules', and a 'blending of egos' (Sawyer, 2017). This appears to be mirrored in the need for shared proximal and coupled motor intentions, in Pacherie's (2012) three-tiered hierarchy of joint agency. Moreover, previous research has illustrated increased interaction increases joint, over self, experiences of agency (Bolt & Loehr, 2017). As such, given the similarity of these characteristics, the lack of any change in agentic state when experiencing group flow was surprising.

This suggests that group flow is related to quantitative, but not qualitative, changes in the sense of agency. To elaborate the lack of change indicates that, during group flow, both self and joint agency are increased. This finding is important when considering who is liable for the outcomes of an action. during such experiential states. If individuals do not experience any self agency over an outcome, they could be considered to have diminished responsibility over their actions, and of their ability to alter the outcomes of an event (Pacherie, 2012). Such an experience would suggest group flow as being a trance like state. However, the present results suggest

both self and joint agency are heightened during group flow, which implicates all individuals as liable for their actions, as well as the outcomes of the activity.

We also predicted that group flow would be dependent on the movement behaviour of participants, with it being increased when engaged in coupled oscillatory containment behaviour. Whilst the observed findings offer some support for this, the results were not consistent. To elaborate, responses to the shortened flow state scale -2 (Jackson & Eklund, 2002) were correlated with increased coupled oscillatory containment behaviour of both the participant and the average value between participant pairs. Interestingly, a larger correlation was observed for combined movement behaviour. This would agree with models of group flow, suggesting that the interaction between co-agents, rather than the actions of the individual, had a large effect on the experiential state. However, the flow state scale is a measure of independent flow. As such, it indicates that participants' experience of independent, as opposed to group, flow was affected by whether the optimum movement strategy was being used by both agents.

In contrast, our other self-report measures indicate that group flow was not correlated with movement behaviour. Both the single point group flow question, and the flow synchronisation scale, did not correlate with the participant's movement behaviour. This is surprising as flow is associated with peak performance, and thus utilisation of the optimum task strategy. The

reason for this lack of effect is unclear. The lack of effect observed with the flow synchronisation scale may be explained by difficulties in translating the scale, originally written in Greek. Nonetheless, it would not justify the lack of effect observed with our single point measure.

Instead, these measures were correlated with task performance. The clearest explanation for this correlation is the balance of skill to task difficulty, which is a key component of flow (Csikszentmihalyi, 1990). It loosely relates to the seventh characteristic of group flow described by Sawyer (2017); a common set of unspoken rules. We suggest that the balancing of skill and difficulty may have affected the influence of movement behaviour on group flow, though further research would be needed to test this hypothesis.

The current study also found support for other characteristics of group flow, related to interacting and communicating with another. Firstly, we observed an effect of trial for all our flow measures, suggesting that developing a common set of unspoken rules, as well as familiarity with one's co-participant, are important for group flow. Secondly, whether subjects had to interact, irrespective of their performance, also had a significant effect on all but one (flow synchronisation scale) of our flow measures. This result further illustrates that subjects must be *interacting* with each other, rather than simply completing actions in the same spatial area, to experience group flow.

Limitations

Several limitations can be seen with the current study, which relate to both the experimental task and the choice of dependent measures. In relation to the task, the Brownian rate and retreat rate of the sheep was set such that full concentration was needed from both participants in order to complete the task. This was due to the need for full concentration in order for flow to emerge (Csikszentmihalyi, 1990; Sawyer, 2017). Nonetheless, our set-up also required participants to oscillate their movements at a high tempo, which added a level of fatigue in participants, and could have counteracted any flow experience. Future research could reduce the Brownian rate and increase the retreat rate, making the sheep move around less erratically, but requiring a larger radius of oscillations in order to be contained.

Also, in relation to our methodology, the mix of survey measures, with a different set of surveys being completed dependent on the trial, reduced the impact of the results. The desire to gain robust subjective experiential reports, within the time constraints of the study, prevented a measure being taken throughout the task. Whilst the reported comparison between first and last trials gives a reliable overview of subject's performance and experience of the task, future research would benefit from using a single group of self-report measures that were taken after each trial.

Some issues can also be seen with the self-report measures that were used. Specifically, our single point measures asked participants about their experience of the sheep, yet no sheep were present in the playback trials. The harmony and control questions found a similar effect of condition, with lower responses being observed in the playback condition for both first and last trial, whilst no difference between condition was observed for agentic state. As response to these questions were not zero, which would be a logical answer as no sheep were present, it appears responses were influenced by their memory of the prior, active, trial. Nonetheless, this interpretation is speculative. Future research would benefit from altering these questions, relating them to participants experience over their own actions - i.e. their sheep dog - instead of the sheep. Nevertheless, these issues do not reduce the importance of the observed findings.

Conclusion and future research

In conclusion, the current study found group flow to be related to *quantitative* but not *qualitative* changes in the sense of agency, with both self and joint agentic states being heightened. This unexpected finding is important, as it suggests that when individuals are engaged in egalitarian joint actions, in which they are likely to experience a sense of group flow, they should be considered responsible for their actions and their outcomes. This differs from other joint actions, such as those which involve a group hierarchy

(Caspar et al., 2016; Obhi & Hall, 2011a; Pfister et al., 2014), in which ones position within the group alters the sense of agency, and thus responsibility, they experience over their actions and the group outcomes.

By adapting the current design, it is hoped that other factors related to the phenomenology of joint action can also be assessed. And, by doing so, we can better understand who is in control when we act with others.

6. General discussion

6.1. Overview

This thesis began by introducing what is currently known about the sense of agency, illustrating both its theoretical underpinnings and how it can be measured (Section 1.2). Then, the sense of agency in a social setting was discussed, with research demonstrating how we may experience both qualitative and quantitative changes in the sense of agency when our actions are nested in a social context (Section 1.3).

The current thesis aimed to assess how aspects of our social world can affect the sense of agency. In the first two experimental sections we considered how altering the social impact of an action may affect the sense of agency. The first section illustrated that, when interacting with another, the outcome of an action has a larger effect on our implicit feeling of agency (as measured by intentional binding). This occurred for both self-produced and observed actions, which we argued indicated a sense of joint agency had emerged between co-agents.

In the second experimental section we illustrated a difference between implicit and explicit measures of agency. Specifically, we found that when acting alone, the financially valenced outcome of each action (which could change on each trial) had little effect on intentional binding, but a significant effect on self-reports of agency. In contrast, whether the beneficiary of each action was oneself or another (fixed within each block of trials) affected

intentional binding, but not self-reports. The difference between the observed findings of these two experimental sections, with outcome valence affecting intentional binding in our joint action and not independent action experiments, illustrates the large mediating effect that the perception of acting with another has on the implicit measure.

Our second two experimental sections considered how interacting with another, with more tightly coupled motor intentions (Pacherie, 2012), causes both qualitative and quantitative changes in the sense of agency. The first of these (section 4) compared how our implicit sense of self agency (as measured by intentional binding) relates to our explicit experience (as measured with self-reports) when acting with others. Our results illustrate that the amount of agency we implicitly feel when acting alone negatively correlates with our explicit experience when acting with others. We have proposed that this shows there is a relationship between our experience of agency when acting alone, and our experience when acting with others, with some individuals naturally experiencing more agency when acting alone.

In our final experimental section, we considered the phenomenology of joint action in more depth. Using the virtual herding task (Nalepka et al., 2016), we assessed the relationship between the sense of agency and group flow. Both factors were shown to be positively correlated with task performance. Also, a strong correlation between them was observed, with

group flow being associated with quantitative, but surprisingly not qualitative, changes in the sense of agency.

Overall, the thesis has illustrated that acting with others alters the effect of sensory cues on our sense of agency. I will now discuss the broader implications of the current thesis in three sections. The first of these will discuss the differences between our results in the first two experimental sections. The second will discuss nuanced aspects of coordinated joint actions which may affect our sense of agency. Then I will turn to models of agency and how they may be adapted in order to reflect agency during joint action.

Finally, I will offer some concluding remarks regarding what we now know about the sense of agency in our social world, and what is yet to be known.

6.2. How the social consequences of an action affect the sense of agency

Our first two experimental sections, which considered how the social consequences of one's actions may affect the sense of agency, differed in two key ways, both in terms of methodology and observed results. In terms of methodology, the first difference relates to the social setting of the action. Our first experimental section involved *joint action*, with two participants completing the task together, whilst our second section involved *individual action*, with one person completing the task alone. The second

methodological difference was the social consequences of the action. In the first section the outcome affected either the active participants or *both* participants. In the second section the outcome affected either the participant or *another* person (chosen by the participant). Different findings, both in terms of the effect of the financial valence of each outcome, and who was affected by each outcome, were also observed between the two sections. Here, we will discuss how the methodological differences between these studies contributed to the reported differences in their findings.

We do not believe that altering the social consequences caused the observed difference in the effect of outcome valence between the two experimental chapters. This is because all experiments included a condition in which just the person acting was affected by the event. If social consequences did influence the effect of outcome valence, similar effects would be expected when the social consequences were the same; i.e. when only the actor was affected. Instead, even when the social consequences were the same, the studies observed different effects.

Instead, we suggest that the difference in outcome valence can be explained by the social setting of the action. Specifically, we argue that awareness of another increased the weighting of external sensory cues on the sense of agency. Support for this can be found by considering two observations from previous research regarding intentional binding. Firstly, previous research which has used financially valenced outcomes, has only

assessed individual action, and has failed to find a reliable effect of valence over a freely chosen action (Di Costa et al., 2017). The lack of an effect observed in our second experimental section, involving individual action, is thus consistent with previous research. The effect observed from our joint action suggests that when acting with another, outcome stimuli have a larger weighting on our temporal perception.

A second previous finding offers further support to this argument. Khalighinejad., et al (2016) conducted a version of the classic intentional binding paradigm (Haggard et al., 2002) in which the participant completed the action either in isolation, or whilst being observed by another person or robot arm. They found that, when our actions are being observed, the perceived time of both actions and outcomes gradually shifts towards the outcome, suggesting an increased weighting of outcome stimuli with repeated exposure. In our study, when interacting with another, and where your actions may affect them, the weighting may be further heightened, resulting in the difference between our two experimental findings. Thus, the difference in the effect of outcome valence was due to the social setting of the action.

In contrast both methodological differences – changing the social context and social consequences - are likely to have contributed to the observed disparity in the effect of social consequences between the two studies. Specifically, they are likely to have caused *qualitative* differences between participants sense of agency. In our individual action binding study,

we observed an effect of social consequences, with increased binding observed for self-interested, compared to pro-social, actions. This suggests we experience more agency over self-interested actions when acting alone. Both methodological differences contributed to this effect: As they were acting alone no joint agency was experienced between themselves and the other beneficiary of their action; and the outcome affected *either* themselves or another, further creating a self-other divide. If the beneficiary had been the participant, or both oneself and another (as observed in the joint-action binding studies), we may not have observed a difference between conditions, as participants would have been affected in both conditions, though this suggestion is purely speculative.

For the joint action binding studies, we have argued (section 2.2.4) that the lack of an effect of social consequences occurred due to the formation of a joint agentic identity between participants. This may have occurred because, along with agents being involved in joint action, the outcome could affect both agents, further reinforcing the perceived co-operation between co-agents. Further support for this can be found in the lack of an effect of task involvement (i.e. Whether participants actively complete or passively observed the action). This mirrors the findings of joint action intentional binding studies, where each of the participant's actions were clearly separable, reported the same null effect of involvement (Engbert et al., 2007; Poonian & Cunnington, 2013; Sahaï et al., 2019).

The lack of difference between active and passive agents in our joint action binding experiments also supports the idea that a vicarious sense of joint agency can occur over observed actions (Sahaï et al., 2019). Specifically, the different effect observed between competitively and co-operatively primed participants illustrates that our *association* with another affects the temporal measure. The results indicate that, when we do not associate with the person acting, intentional binding was affected more by outcome valence. In contrast when participants associate with the action (i.e. co-operative prime), both action and outcome cues had a similar effect on intentional binding, regardless of their objective level of involvement. As such, by determining the extent to which action and outcome sensory cues appear to have affected the temporal measure, intentional binding may be a useful measure of joint agency during joint action; allowing a vicarious sense of agency to be recorded, even in those who may not be directly involved in an event.

In sum, our first two experimental sections have illustrated how acting with another, compared to acting alone, can affect the weighting of external sensory cues on the sense of agency. Moreover, we showed that our relationship with another can have a *qualitative* effect on the sense of agency, with joint agency being experienced when co-operating, but not when competing, with another person. We also found that those passively involved in the event can experience joint agency. Overall, the findings show that, even

without co-ordinating our actions together, our relationship with others, and how we affect them, has both qualitative and quantitative effects on the sense of agency.

In the next section I will consider our explicit sense of agency when co-ordinating our actions with another.

6.3. Agency in co-ordinated joint actions

The second two experimental sections of this thesis assessed the sense of agency during co-ordinated joint actions; where participants are engaged in more closely coupled motor intentions. In section 4 we compared our sense of agency when acting alone to that experienced when acting with others to complete a haptic task. In our final experimental section (section 5), we implemented the virtual herding task to assess the relationship between the sense of agency and group flow during joint action. We have argued that the observed findings in the haptic task illustrate a *qualitative* change in the sense of agency, with subjects experiencing more joint agency when performance improved. In contrast, in the virtual herding task performance was related to a *quantitative*, but not qualitative change in the sense of agency. Understanding what caused the difference between these two studies is important, especially when considering who should be held morally responsible in egalitarian joint action. The current section will discuss how

the methodological differences between these two studies contributed to the reported differences between their findings.

The joint action being completed in the two sections differed in multiple ways. Firstly, movement flexibility was much higher during the virtual herding task. The haptic task was highly structured, with a specific action required and little variation in action possible. In the virtual herding task participants made more complex actions, with a wide variety of possible actions to choose from. However, the lack of movement flexibility made the optimum strategy much clearer in the haptic task. In the virtual herding task participants had to discover the correct strategy for themselves. The observed effect of performance on agency in the haptic task also occurred after first acting independently, whilst no mental comparison against performance when acting independently was available during the virtual herding task. Finally, no feedback was given for the haptic task, whilst participants were given precise feedback on their performance after each trial in the virtual herding task.

Whilst all of these factors will have affected their subjective experience, a few may have been key in causing the qualitative differences observed between the two studies. Specifically, the degree to which participants had to discover the optimum strategy independently may have altered the extent to which they felt self-agency as their actions became more coupled, indicating better performance. Participants' actions in the haptic task

were highly structured, whereas actions in the virtual herding task were more freely chosen. Thus, as performance improved, and their actions became more coupled, those who felt less freedom over the chosen action may have felt less self-agency.

This difference illustrates some of the more nuanced aspects of Pacherie's (2012) discussion of self and joint agency. The difference between our final two studies suggests that when we learn to synchronise our actions in a highly structured manner (haptic task) we will feel we-agency (joint agency without self agency), whilst when we synchronise our actions in a more organic manner (virtual herding task) we may experience shared-agency (joint agency with self agency). However, both involve participants performing similar actions, with similar effects, with a high degree of synchrony between them. As such, we would expect we-agency, yet we have reported two different agentic states.

The different agentic states observed in these two studies thus shows how motivational and socioemotional factors can also affect our agentic state. To elaborate, as participants in the group flow task had to discover the optimum joint action for themselves, increasing the creativity needed, with the action decided implicitly by the participant, rather than dictated by the experimenter, they may have considered their actions to have a higher positive value, and thus have an increased experience of self-agency. The

importance of this difference was highlighted by Pacherie, in discussing the sense of agency a factory worker and a violinist may feel:

> "[If] cognitive cues…were the only determinants of the experience of agency in joint action, we should expect a second violin in an orchestra to experience as little agency for the joint performance of the Eroica as the factory worker on the assembly line for the manufacturing of a dishwasher…The musician, however, is probably more likely to attribute high positive value to the performance of a great musical work than the factory worker to the manufacturing of a household appliance."
> (Pacherie, 2012, p. 378)

Thus, our perception of the task being completed may also affect the sense of agency we experience over it. The difference between these two agentic states belies the larger issue of moral responsibility.

When we do not consider ourselves to be in control of our actions, we also do not consider ourselves morally responsible for their effects. This allows soldiers to act without feeling the moral weight of their actions and is key in determining if someone is liable for their actions in courts of law. In hierarchical joint actions moral responsibility can be more easily determined; i.e. who gave the order? But in egalitarian actions it becomes harder, as we may be experiencing a number of different agentic states over the joint action.

The agentic state one is experiencing depends on a wide variety of factors. The current results have shown that the degree of flexibility one experiences over their actions can alter their agentic state. Those with a high degree of flexibility, and a sense that they have *freely chosen* the actions by themselves, may experience shared agency and should thus be considered morally responsible over their involvement in such joint actions. In contrast, when the actions are highly structured, individuals may not be as responsible for their actions.

Understanding how the numerous other aspects of our social world alter our agentic identity must be a key focus of future research; allowing us to determine who is in control when we act together. Determining how to incorporate such factors in models of agency is what I shall now turn to.

6.4 Models of agency in a social context

Current models of the sense of agency only consider actions completed in isolation; i.e. without considering the social context of an action. We have added to this by showing how, when our actions are nested in our social world, the weighting of sensory cues which affect the sense of agency can change. Moreover, our agentic experience itself can shift.

This has implications for models of agency. For example, internal forward models, such as the comparator model (Blakemore, Wolpert, & Frith 2002), argue that our sense of agency is intimately tied to the predictions

made by our motor system. As such, the wider implications of our actions (e.g. its social consequences), or the environment the action is completed in, are not considered to have a large effect. What is considered important for sense of agency over exteroceptive events, is whether the event was predicted by the efferent copy of the action one produced.

In contrast, Wegner's (2002) theory of apparent mental causation has argued that whether we experience a sense of agency over our actions will be more dependent on external, environmental factors, rather than internal models of our motor commands. It suggests that, if a sensory event occurs, and it appears oneself is the most likely cause for it, we will experience a sense of agency over it. Again, however, this model does not consider the wider implications of one's actions to be inherently important.

Nonetheless, the empirical research presented in this thesis, as well as much recent published work (Beyer et al., 2016; Bolt & Loehr, 2017; Caspar et al., 2016; Le Bars et al., 2020; Obhi & Hall, 2011a; Pfister et al., 2014; Sahaï et al., 2019; van der Wel et al., 2012) has shown that a wide range of social factors can affect the sense of agency. As such, a model which considers the impact social factors have on the sense of agency is required. To this end, Bayesian style cue integration models (Moore & Fletcher, 2012) appear the most practical method of adding and integrating the increasing number of sensory cues related to one's agentic experience. These models give each sensory input a different weighting in terms of its impact on the

sense of agency. Importantly, they also allow for the weighting of sensory cues to be adjusted in response to the addition or subtraction of other sensory cues. Such models have already been used to account for changes in the weighting of external stimuli in response to their reliability (Moore & Haggard, 2008), and could be adapted for social agency studies. Using this method, sensory cues, such as how closely we associate with the beneficiary of an action, can be easily added and their importance weighed in relation to other sensory cues. Moreover, how the weighting of such cues is affected by others can also be computed, such as the effect of social context (e.g. individual or joint action). Such a method could also, theoretically, be used to create computational models of the sense of agency, in which the observed effects of human studies could be recreated. Creating such models would be hugely beneficial to current understanding of the sense of agency; making it easier to apply research in the real world.

One issue with creating such models for social aspects of agency, is the increased number of dimensions along which the cognitive mechanism can vary. For individual action, the amount of agency an individual experiences can vary at either and implicit or explicit conceptual level (Synofzik et al., 2008a). When we act with others, however, our agentic state may also vary, such that we can have both a sense of self and a sense of joint agency (Pacherie, 2012). The extent to which both of these agentic states are experienced can vary independently, giving rise to shared or we agency

experiences. Moreover, they may occur at either conceptual level; e.g. we may implicitly *feel* self-agency over our action but have an explicit *judgement* of joint agency over the outcome.

For example, our individual action intentional binding study observed implicit and explicit measures of the sense of agency to be affected by different sensory cues. However, the effect of sensory cues on intentional binding changed when acting with others, suggesting it may be related to joint agency. Previous research which has used the implicit measure has also suggested that it is indicative of a joint agentic identity (Obhi & Hall, 2011a; Sahaï et al., 2019). However, when our actions are nested within a hierarchical social context, researchers have argued that intentional binding indicates an enhanced sense of self agency (Pfister et al., 2014).

Thus, it is clear more research is needed to understand what aspect of our agentic identity the implicit measure is related to in different settings. Interestingly, when acting with others, we observed that outcome valence did affect intentional binding, whilst it did not during individual action. This suggests separate cue integration models would be needed for each conceptual level of the sense of agency, as well as the different agentic states that can be experienced. As such, there may currently be too many unknown variables to make accurate models of agency in our real, social, world. However, as empirical research continues to understand the complex way our

social world can affect our sense of agency, or mediate the impact of other sensory cues, it is likely new models of agency will be proposed.

6.5. Concluding remarks

To conclude, the way we perceive our actions in relation to our social world can have a drastic effect on our experience of them. Throughout this thesis I have highlighted the impact several aspects of our social world can have on our sense of agency. These studies have shown that even when passively involved in an action we can experience a sense of joint agency over the action, and that how we perceive another influences the weighting of sensory cues. I have also shown that the perceived importance of an action can cause qualitative changes in the sense of agency: in some settings we may feel shared-agency over an event, and thus have some degree of responsibility for its affects, in others we may not experience a sense of agency of the joint action and thus do not consider ourselves responsible for its effects.

In sum, what we do with others, and how we do it, has both qualitative and quantitative effects on the sense of agency.

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Appendices

Appendix 1: Friendship questionnaire

Friendship Questionnaire

PARTICIPANT NO: __

Age:

Gender:

Please circle your answers

1) Are you related?

YES	NO

2) With 1 being a passing acquaintance and 7 being your best friend, how close a friend are you with the other participant?

1	2	3	4	5

3) How long have you known the other participant?

Just met	1 Month +	1 Month +	3 Years+	10 Years +

4) How much time do you spend with the other participant on average in a week?

None	10 minutes +	1 hour +	5 hours +	20 hours +

5) Where do you **most often** see the other participant (pick one)?

University	Work	Home	Social events	Other please specify

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……

Appendix 2: Short Flow State Scale – 2

Question
I feel I am competent enough to meet the high demands of the situation.
I do things spontaneously and automatically without having to think.
I have a strong sense of what I want to do.
I have a good idea while I am performing about how well I am doing.
I am completely focused on the task at hand.
I have a feeling of total control over what I am doing.
I was not worried about what others may have been thinking of me.
The way time passes seems to be different from normal.
The experience was extremely rewarding.

Note. These questions were answers on a five-point "Agreement" scale, with the options of "Disagree strongly," "Disagree," Neither Agree nor Disagree," "Agree," and "Agree Strongly." Each question relates to one of the nine dimensions of the individual flow experience first identified by Csikszentmihalyi (1990).

Appendix 3: Flow Synchronisation Scale

Question
1. I felt that I had a positive impact on the task solving of my partner
2. At the end of the task, I felt myself more energized than at the beginning of it.
3. My partner motivated me while we carried out the task.
4. We were able to communicate well during the activity.
5. The performance of my partner encouraged me.
6. I felt the trust between us.
7. I have picked up new tricks from my partner.
8. I felt we were the reflection of each other.
9. I felt my actions were accordant to my partner's.
10. I felt that we performed well.
11. I concentrated on nothing but the common activity.
12. I would work together with my partner another time.
13. I motivated my partner while we carried out the task.
14. I felt the rapport between us.
15. We coordinated our actions.
16. I felt that my relationship with my partner has improved.
17. I felt that I could count on my partner.
18. I would work together with my partner in the future.
19. We were able to cooperate automatically.
20. I could respond well to my partner's behavior.
21. I was preoccupied with the activity.
22. I felt that I had a positive impact on the performance of my partner.
23. I felt like we were almost in perfect harmony.
24. Doing the task recharged my batteries.
25. I could learn from my partner.

26. I was able to accept my partner's capabilities.

27. We cooperated well.

28. I completely switched off.

Note. These questions were answered on a five-point scale that allowed participants to indicate the degree to which they experienced group flow, with the options of "Not at all," "A little," "Neutral," "Somewhat," and "Totally." Questions selected for their relevance to the experience of group flow.

Dimensions described by Flow Synchronisation Scale

Dimension	Question
Synchronisation and effective cooperation with group members	4, 6, 10, 12, 14, 16, 17, 18, 19, 20, 26, 27
Experience of engagement and concentration	2, 11, 21, 24, 28
Individual motivation and learning	3, 5, 7, 25
Motivation and positive impact on partner	1, 13, 22
Coordination with partner during activity	8, 9, 15, 23

Appendix 4: Sense of Agency Scale

Question
1. I am in full control of what I do.
2. I am just an instrument in the hands of somebody or something else.
3. My actions just happen without my intention.
4. I am the author of my actions.
5. The consequences of my actions feel like they don't logically follow my actions.
6. My movements are automatic—my body simply makes them.
7. The outcomes of my actions generally surprise me.
8. Things I do are subject only to my free will.
9. The decision whether and when to act is within my hands.
10. Nothing I do is actually voluntary.
11. While I am in action, I feel like I am a remote-controlled robot.
12. My behaviour is planned by me from the very beginning to the very end.
13. I am completely responsible for everything that results.

Appendix 5: Single point survey questions

Question
1. How strongly do you feel you are working in harmony with the other player?
2. How strongly do you experience being in control over the movement of the sheep?
3. How much ownership do you take over the movement of the sheep?
Rate your feelings of control over the herding of the sheep on a scale from 01 (shared control) to 99 (independent control).

Note. These questions were answered on a seven-point scale from 1 to 7, except the final question which was answered between 1 and 99.