THE SENSE OF JOINT AGENCY
IN JOINT ACTION

A Thesis Submitted to the College of
Graduate Studies and Research
in Partial Fulfillment of the Requirements
for the Degree of Master of Arts
in the Department of Psychology
University of Saskatchewan
Saskatoon

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ABSTRACT

The *sense of agency* refers to the feeling of generating and controlling actions and their effects. Philosophers have proposed that when people coordinate their actions with others they may experience a sense of joint agency, or shared control over actions and their effects. However, little empirical work has investigated the sense of joint agency. Therefore, the primary goal of the present research was to directly examine people's experiences of joint agency. In a series of experiments, we manipulated factors hypothesized to influence joint agency, and employed rating scales that asked participants specifically about their experience of joint agency. In Experiment 1, pairs of people coordinated their actions to produce tone sequences and then rated their sense of joint agency on a scale ranging from shared to independent control. People felt more shared than independent control overall, confirming that people experience joint agency during joint action. Furthermore, people felt stronger joint agency when they: a) produced sequences that required mutual coordination compared to sequences in which only one partner had to coordinate with the other, and b) held the role of follower compared to leader. Because joint agency is thought to include not only a sense of shared control over a continuous action, but also a sense of shared responsibility for action outcomes, in Experiment 2 we examined whether the same factors would influence people's sense of shared responsibility for joint action outcomes. Participants rated their responsibility on a scale with endpoints indicating they were responsible (self-responsibility) or their partner was responsible (other-responsibility), and a midpoint indicating they both were responsible (shared responsibility). People felt more shared responsibility for correct outcomes and more self-responsibility for incorrect outcomes, regardless of the type of coordination or role they held within the joint action. Finally, in Experiment 3 we examined whether the predictability of a partner's actions influenced the sense of shared control. Each participant coordinated with two confederate partners, the timing of whose actions was manipulated so that one partner's actions were highly predictable in time and the other's less predictable. People felt more shared control when they coordinated with the more predictable partner, even after controlling for joint performance accuracy and variability of the participant's action timing. The results from these three experiments indicate that the sense of joint control is driven by people's predictions about their partner's actions, whereas joint responsibility is more strongly influenced by outcome valence. These finding have implications for theories of joint agency as well as our understanding of self-agency and everyday joint action.

ACKNOWLEDGEMENTS

I would first like to thank my supervisor, Dr. Janeen Loehr, for her exceptional mentorship for the duration of my thesis work. Thank you, Janeen, for always responding quickly and thoroughly to my questions, for being a great role model, and for offering insightful advice. I would also like to thank my committee members, Dr. Ron Borowsky and Dr. Steven Prime, for their helpful suggestions and ideas which shaped my thesis research and writing. I would also like to thank my external examiner, Dr. Regan Mandryk, for offering novel ideas and expanding my research perspective. I would also like to acknowledge my friends and family for constant support throughout the duration of my thesis work and in everything I do. Lastly, I would like to thank my husband, Devin Bolt, for his unconditional support and willingness to discuss ideas, thoughts, and issues. Thank you for always having my back.

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LIST OF ABBREVIATIONS

-2LL	-2 log-likelihood
ASD	Autism spectrum disorder
CM	Comparator model
EEG	Electroencephalography
ERP	Event-related potential
FSR	Force-sensitive resister
ITI	Inter-tap interval
LRT	Likelihood ratio test

CHAPTER 1

AN INTRODUCTION TO THE SENSE OF JOINT AGENCY IN JOINT ACTION

Portions of this chapter are based on the following journal manuscripts:

Bolt, N. K., Poncelet, E. M., Schultz, B. G., Loehr, J. D. (2016). Mutual coordination strengthens the sense of joint agency in cooperative joint action. Manuscript submitted to *Consciousness and Cognition.*

Bolt, N. K., & Loehr, J. D. (2016). The predictability of a partner's actions modulates the sense of joint agency. Manuscript submitted to *Cognition*.

The *sense of agency* refers to the feeling of generating and controlling actions and their effects (Haggard & Tsakiris, 2009). For example, when someone turns on a light, they have a sense of agency over flicking the light switch and causing the light to come on. Previous research has shown that the sense of agency is driven by both predictive processes (e.g., internal predictions about an action based on an efference copy) and postdictive inferences (e.g., visual feedback about the consequences of an action) at different levels of action specification (Moore & Haggard, 2008; Pacherie, 2008; Synofzik, Vosgerau, & Voss, 2013). However, most research on the sense of agency has focused on individuals performing tasks alone. Little research has investigated agency during *joint action*, when two or more individuals coordinate their actions to achieve a shared goal (Sebanz, Bekkering, & Knoblich, 2006). Philosophers have proposed that the experience of agency during joint action might be substantially different than during solo action (e.g., Pacherie, 2012). In addition to experiencing a sense of *self*-agency over actions and their effects (e.g., a sense that "I did it"), people may also experience a sense of *joint* agency over actions and effects (e.g., a sense that "we did it"). To date, no research has examined the sense of joint agency during joint action. The sense of joint agency may rely on similar cues as self-agency. However, these cues need to be understood not only as they pertain to one's own actions, but also in relation to a co-performer's actions and/or the joint action as a whole. Using insight from empirical investigations of self-agency and joint action, and theoretical work on the sense of joint agency, the current research offers the first investigation into people's experience of joint agency when they engage in cooperative joint action.

Self-agency: Cues and Cue Integration

Researchers have investigated a number of potential cues that people use to determine their sense of self-agency over actions and effects. These cues range from low-level sensorimotor information to cognitive inferences about action production (Pacherie, 2008). Two main theories, the comparator model (CM; Frith, Blakemore, & Wolpert, 2000) and Wegner's theory of apparent mental causation (AMC; Wegner, 2002), attempt to classify these cues and provide an explanation for how they contribute to the sense of self-agency. These theories, and recent frameworks that integrate these two theories, are discussed next.

According to the CM, the sense of self-agency relies on congruence between private sensorimotor predictions generated about an action, and the actual consequences of the action (Blakemore, Frith, & Wolpert, 1999; Frith et al., 2000). Predictions are generated via forward models of action control (Wolpert & Flanagan, 2001; Wolpert, Ghahramani, Jordan, 1995). When a person initiates an action, a motor signal is sent from the brain to produce the action. Simultaneously, an efference (forward predictor) copy of this motor signal is triggered that simulates the consequences of the motor signal. The internal prediction is compared to the actual sensory feedback from an action (reafference). The closer the match between the internal prediction and the actual sensory consequences, the stronger the sense of self-agency one feels. On the other hand, when there is a mismatch, people's sense of self-agency is reduced and they may attribute the action and/or effect to an external cause. Central to the CM is the sensorimotor predictive component (Synofzik, 2015). Sensorimotor information is only available when an action is internally generated. Therefore, it provides an important signal for determining if an outcome is the result of one's own actions. Evidence for the CM account of agency comes from the finding that disrupting the consequences of an action, for example, by increasing the temporal delay or altering the expected frequency of a tone elicited by an action, disrupts the sense of self-agency (Sato & Yasuda, 2005).

However, private sensorimotor information may not be necessary to make predictions about the consequences of an action and develop a sense of self-agency (Knoblich & Repp, 2009; Pacherie, 2008). Typically, when sensorimotor information is present, perceptual information about our movements (e.g., visual or auditory feedback about where our hand is in space) is also available. Therefore, people may use perceptual information to make predictions about the consequences of an action and compare these predictions to actual consequences to determine their sense of self-agency. Evidence for this claim comes from a study by Knoblich and Repp (2009). In a series of experiments, people had to distinguish between self- and externally-produced tones during active tapping and during passive listening to a previously recorded trial. People were better at discriminating self-produced actions from externally-produced actions when both sensorimotor and perceptual cues were available (i.e., when they were actively tapping), but could still make the discrimination when sensorimotor information was not available (i.e., when passively listening to tones they had previously produced). In the latter case, the researchers found that people used perceptual information, such as tempo changes, to discriminate self- from externally-produced tones. Together, these findings suggest that both sensorimotor and perceptual cues contribute to people's sense of self-agency (Knoblich & Repp, 2009; Pacherie, 2008).

The theory of AMC claims that cognitive inferences and beliefs about action causation underlie the sense of self-agency rather than low-level sensorimotor or perceptual predictions (Wegner, 2002). According to this theory, agency arises from the congruence between a prior thought and an observed action when the thought/intention occurs before the action (priority), is consistent with the action (consistency), and there are no alternative causes for the action (exclusivity). In line with this theory, Wegner and Wheatley (1999) demonstrated that the timing of a thought in relation to an action influences the sense of self-agency. People felt more self-agency over having caused a cursor to stop on an object when they heard a word describing that object immediately prior to its appearance on screen, compared to hearing the word further in advance or immediately after the appearance of the object (Wegner & Wheatley, 1999). Additionally, increasing the consistency between an action and its outcome by presenting primes that were congruent with the action outcome decreased the perceived interval between the action and the effect (i.e., the intentional binding phenomenon; Moore, Wegner, and Haggard, 2009). Although intentional binding has been interpreted as an implicit measure of self-agency, the degree to which it correlates with explicit judgments of self-agency remains unclear (Dewey & Knoblich, 2014). However, even if intentional binding is not equivalent to explicit judgments of self-agency, it could still contribute to the experience of agency and causality (Gentsch & Synofzik, 2014). Taken together, these studies suggest that people's self-agency for an action depends on the congruence between their prior thoughts and subsequent consequences of the action.

In the past decade, it has become apparent that neither the CM nor the theory of AMC can alone account for the sense of self-agency (Pacherie, 2007). No single cue is powerful enough to explain self-agency under all conditions (Synofzik, Vosgerau, & Linder, 2009). Instead, the sense of self-agency may be better explained by a combination of these accounts. Pacherie (2008) proposes that the experience of self-agency relies on the congruence between predicted and actual consequences at all three levels of action specification: sensorimotor, perceptual, and cognitive. Furthermore, other researchers have proposed that these cues are integrated in the brain by optimal cue integration, whereby predictions and consequences at each level of action specification are weighted depending their reliability and availability, and are used in combination to establish the most accurate agency representation (Moore & Haggard, 2008; Synofzik et al., 2009; Synofzik & Voss, 2010). For example, if a force is applied to a person's finger by an experimenter using a cord and pulley beneath a keyboard to initiate a button press, sensorimotor information used to generate the action is absent, and cognitive information, such as a prime presented before the action, is given more weight in determining one's sense of self-agency over the effect (Moore et al., 2009). Cue integration may also be influenced by emotional and attentional factors (Gentsch & Synofzik, 2014). For example, people display a self-serving bias whereby they are more likely to take responsibility for successful outcomes compared to unsuccessful outcomes (Mezulis, Abramson, Hyde, & Hankin, 2004; Miller & Ross, 1975). Intentional binding is also greater for positive compared to negative outcomes (Takahata et al., 2012; Yoshie & Haggard, 2013). These findings suggest that cues are weighted differently depending on their valence, possibly because people pay more attention to expected successful outcomes compared to unsuccessful outcomes to promote positive self-concept (Gentsch & Synofzik, 2014).

In sum, people derive their sense of self-agency from a multiplicity of cues at different levels of action specification (sensorimotor, perceptual, and cognitive). Congruence between the predicted and actual effects at each level of action specification strengthens the sense of self-agency (Pacherie, 2008). Furthermore, these predictive and postdictive cues receive different weight in their contribution to the sense of self-agency depending on their reliability, availability, and valence (Gentsch & Synofzik, 2014; Moore & Haggard, 2008). Pacherie (2012) proposes that these cues might also play a role in deriving a sense of joint agency. However, joint agency is more complex than self-agency because joint actions require people to predict the consequences of their partner's actions and the joint action, in addition to predicting the consequences of their own actions (Pacherie, 2012). The next section discusses how people make these predictions during joint action.

Joint Action: Representation, Prediction, and Integration

Perception and action are closely linked (Prinz, 1997), and this close link allows people to match the actions they perceive onto their own motor repertoire. Evidence for this claim was first demonstrated in monkeys, whereby groups of neurons (referred to as mirror neurons) were found to fire both when the monkey executed an action and when the monkey perceived an experimenter producing that action (Rizzolatti, Fadiga, Gallese & Fogassi, 1996). In humans, similar brain regions are active when an action is executed and perceived (Rizzolatti & Craighero, 2004). For example, watching someone produce complex dance movements activates the observer's action system, and this activation is further facilitated when the observer has previous experience performing such movements (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005). In the context of joint action, close links between perception and action allow people to represent others' actions in equivalent ways as their own actions, even when attending to their partner's actions is not necessary to the joint goal (Sebanz, Knoblich, & Prinz, 2003).

Keller, Novembre, and Loehr (in press) propose an integrated model of action production that includes internal models for self-, other-, and jointly-produced action effects. The internal model for self-produced actions is the same as the forward model of action control discussed in the previous section. This model runs in parallel with the internal model for other-produced actions, whereby other people's actions are predicted by motor simulation and compared to the consequences of their actions (Wilson & Knoblich, 2005; Wolpert, Doya, & Kawato, 2003). The internal model for other-produced actions allows people to adjust their own actions based on any discrepancies between internal predictions and actual consequences of their partner's actions, thereby facilitating interpersonal coordination (van der Steen & Keller, 2013). Evidence for the claim that people predict both their own and others' actions using parallel internal models comes from the finding that people show the same neural responses to altered auditory feedback elicited by their own and their partner's key presses during synchronized duet music performance (Loehr, Kourtis, Vesper, Sebanz, & Knoblich, 2013). People are also better able to coordinate with co-performers whose actions are more similar to their own (Loehr & Palmer, 2011; Zamm, Wellman, & Palmer, 2016). Furthermore, Kourtis, Sebanz, & Knoblich (2013) showed that predictions of other people’s actions are modulated by social interaction. They had pairs of participants engage in a cooperative coordination task while being monitored by electroencephalography (EEG). Anticipatory motor activity was stronger when people anticipated an interaction partner’s action execution, compared to when they anticipated a non-partner’s action execution. Thus, the degree to which people simulate their partner’s actions depends on their social relationship with that partner.

Keller et al.’s (in press) model also proposes that the internal models for self and other interact to form an internal model for joint actions. Predicted states for self and other are combined to form a joint predicted state, and this is compared to the combined joint consequences that result from self- and other-produced actions. Vesper, Knoblich, & Sebanz (2014) provided evidence for this component of the model by having participants imagine jumping to a target alone or synchronizing their landing times with a partner. The duration of a participant’s own imagined jump was influenced by the distance of their partner’s imagined jump. This finding suggests that people can integrate different simulations in joint action, and use these to adjust their own actions. According to Keller et al., the main purpose of the internal model for joint actions is to anticipate and correct for errors in joint action before they occur.

In sum, people represent and predict self- and other-produced actions using parallel internal models during cooperative joint action. According to Keller et al. (in press), predictions and consequences for self- and other- produced actions are integrated to make predictions about the joint action. These joint-predictions are then compared to consequences that result from the joint action. Philosophers have proposed that the sense of joint agency relies upon predictions of others’ actions and the joint action (Pacherie, 2012, 2014). The next section discusses these theoretical accounts of joint agency in joint action.

Philosophical Accounts of Joint Agency

Gallotti and Frith (2013) proposed that when people coordinate their actions, they engage in a collective mode of cognition called the *we-mode*. The main idea of the we-mode is that co-performers represent their actions as something they are going to pursue together, as a single unit. This way of cognizing is hypothesized to enlarge people’s potential for action by giving them access to more information about their partners’ behavior than they would have as mere disembodied observers. This information provides new possibilities for action, allowing people to bring about actions and effects they could not accomplish individually and expanding their agency scope (Pacherie, 2012). For example, two people may be able to lift a heavy object that neither person could lift alone.

Cognition in the we-mode may lead to feelings of joint agency (Dewey, Pacherie, & Knoblich, 2014). Dokic (2010) defines joint agency as "the perceptual sense that we are acting together" (p. 40). Similarly, Seeman (2009) proposes that joint action will involve "a sense of acting together … [which] amounts to a sense of joint control" (p. 504). Pacherie (2012) provides the most specific definition of joint agency, describing it as the sense that one's contribution to a joint goal is equal to the contributions of one's co-performers and that one's coordination relations with co-performers are relatively symmetrical. Pacherie proposes that joint agency may be experienced in two forms: *shared agency*, whereby people experience a sense of joint agency along with an intact sense of self-agency, and *we-agency*, whereby the experience of joint agency is accompanied by a reduction in self-agency. We-agency is thought to be experienced when co-performers produce similar actions with similar effects and synchronous timing. For example, soldiers marching in step may experience a loss of self-agency as their actions become one with the group (McNeill, 1995). However, most everyday joint actions are thought to involve shared agency, as they typically require people to produce coordinated yet distinct and complementary actions.

Pacherie (2012) proposes an integrative framework for how people experience joint agency. Similar to self-agency, she proposes that joint agency relies on a match between predicted and actual consequences at three levels of action specification: cognitive, perceptual, and sensorimotor. However, this becomes much more complex in joint action because people must not only predict the consequences of their own actions (self-predictions) at these three levels, but also the consequences of their partner's actions (other-predictions) and their combined actions (joint-predictions) at each level of action specification. Overall, then, the sense of joint-agency relies on congruence between joint-predictions and effects, which in turn relies on the accuracy of self- and other-predictions. Internal models that extend to joint action allow people to compare other- and joint-predictions with actual outcomes at different levels of action specification (Keller et al., in press). However, because people have access to perceptual but not sensory reafferent information about their partners' actions, perceptual and cognitive outcomes likely have a greater role than sensorimotor predictions in the experience of agency during joint action (Pacherie, 2012; van der Wel & Knoblich, 2013).

Pacherie (2012) also describes different factors that might influence people's sense of joint agency by impacting their ability to make accurate predictions at the three levels of action specification. First, joint agency is expected to be influenced by whether a joint action is egalitarian or hierarchal in structure. Specifically, if contributions to the joint action are equal, partners share knowledge about each other's tasks and how they contribute to the joint goal, increasing the congruence of people's cognitive predictions and strengthening the sense of joint agency. Second, joint agency is expected to be influenced by the scale of a joint action. In small-scale joint actions (with fewer people), people are able to monitor what their co-performers are doing and what the perceptual consequences of their actions are, increasing the congruence of their perceptual predictions. Another factor is the distribution of roles in the joint action. When co-performers have nearly identical and interchangeable roles, they can form more accurate sensorimotor predictions about their partner's actions. However, even small differences in the salience of people's roles may weaken their sense of joint agency. For example, the person who acts first may perceive themselves as the leader of the joint action (Wegner & Sparrow, 2007) and therefore may experience a weaker sense of joint agency. One last factor is coordination symmetry between co-performers. When coordination is symmetrical (e.g., both people have to adapt their own actions to their co-performers' actions), people may form more accurate sensorimotor predictions about their partner's actions, compared to when coordination is asymmetrical (i.e., only one person has to adapt to their partner but not vice versa). In sum, Pacherie predicts that, for small-scale joint actions, the sense of joint agency will be strongest in situations where individual contributions are of similar importance to the joint goal, where there is little distinction between roles, and where both people coordinate with each other rather than one person coordinating and the other being coordinated.

Despite recent theoretical work on joint agency, empirical investigations into the factors that influence the sense of joint agency are limited. In the next section, we discuss the handful of studies that have examined agency during joint action, all of which have either specifically examined self-agency in joint action or were ambiguous as to whether they asked participants to rate self- or joint agency.

Empirical Investigations of Agency in Joint Action

A handful of studies has examined people's experiences of agency during cooperative joint action. In line with theoretical proposals that the sense of agency involves both a sense of *continuous control* over an *action* and a sense of *causal responsibility* over having produced an *outcome* (Pacherie, 2007), some studies have focused on people's sense of control over joint actions and effects that unfold over time (Dewey et al., 2014; van der Wel, 2015; van der Wel, Sebanz, & Knoblich, 2012), whereas other studies have focused on people's sense of responsibility or causation over a joint action outcome (Dewey & Carr, 2013; Obhi & Hall, 2011). Investigations focused on control over an action have been ambiguous as to whether they measured self-agency, joint agency, or a mixture of the two. For example, studies have asked participants to rate statements such as "how strongly they had experienced to be in control" (van der Wel et al., 2012) or "how effective was your joystick at controlling the dot?" (Dewey et al., 2014). These statements are ambiguous because they may prompt people to rate their experience of control at a group level rather than as an individual (Dewey et al., 2014). Investigations focused on the sense of responsibility over an outcome have primarily focused on self-agency. For example, Dewey and Carr (2013) asked participants "did you produce the tone?" and had them respond on a scale from "definitely not" to "definitely". Although these previous studies have not directly asked people about their sense of joint agency, they provide indirect support for some of the theoretical predictions about joint agency described in the previous section.

First, there is indirect support for the prediction that people will experience joint agency when they engage in cooperative joint action. Researchers have found that people's sense of control over a continuous joint action depends on both partners' combined contributions rather than only their own individual contributions. For example, Van der Wel (2015) had pairs of participants coordinate their joystick movements to move a single dot from the center of the screen to one of two target areas. Ratings of control were equally high for the partner who chose which target to move to and for the partner who followed the other's choice. Similarly, Dewey et al. (2014) had pairs of participants use joysticks to keep a cursor centered on a moving target. The participants could not see their partner's joystick and were informed that the movement of the cursor could be influenced by their own joystick, their partner's joystick, random perturbations (noise), or any combination of the three. Participants' ratings of control were higher when both participants' actions contributed to the movement of the cursor (i.e., both joysticks were turned on) compared to when only one participant's actions contributed to its movement (i.e., only their own or their partner's joystick was turned on), as long as participants' contributions were distinguishable (e.g., each was responsible for one movement direction).

These findings indicate that people may have evaluated their sense of control at the group level rather than at the individual level ("we are in control"; Dewey et al., 2014), since their sense of control depended on both partners' combined contributions.

Second, there is indirect support for the prediction that joint agency relies on predictions about the perceptual effects of a joint action. We would expect that if joint agency relies on perceptual predictions, people would feel more joint agency the better they perform, since actions are easier to predict the better people perform (van der Wel, 2015). Consistent with this prediction, Van der Wel (2015) showed that participants' ratings of control were positively correlated with the smoothness of both their own movements and their partner's movements. Furthermore, Van der Wel et al. (2012) showed that when pairs coordinated their actions to move a pole back and forth between two targets, each individual's ratings of control were positively correlated with pair-level task accuracy but not with the amount of force exerted by each individual. Both of these studies are consistent with the hypothesis that in joint action, agency may be based predominantly on comparisons between expected and actual perceptual information, to which both people have access, rather than sensorimotor information, to which only individuals have access (see also van der Wel & Knoblich, 2013).

Lastly, there is indirect support for the prediction that people's role in a joint action influences their sense of agency. Specifically, two studies have examined how people's role in a joint action affects their sense of responsibility for action outcomes. Obhi and Hall (2011) had pairs of participants coordinate their actions to depress a single button, which evoked a tone. Participants either initiated the button press (leaders) or passively moved their finger along with the button after their partner had initiated the press (followers). Participants' ratings of responsibility for producing the tone were polarized such that leaders felt entirely responsible whereas followers felt completely not responsible. Dewey and Carr (2013) had pairs of participants produce either the first button press (leaders) or the second button press (followers) in a two-press sequence. A single tone was evoked at a variable delay after the second button press, and participants rated whether they or their partner had produced the tone. In this study, followers felt more self-agency (and were rated as having more other-agency) compared to leaders, likely because the follower's button press occurred closest in time to the tone and was therefore perceived as having caused it. Together, these studies suggest that people's roles within a joint action affect their experiences of responsibility for joint action outcomes.

In sum, empirical investigations of agency during joint action provide some support for the theoretical predictions that people may experience a sense of joint agency that is influenced by perceptual information and people's role within the joint action. However, this interpretation remains tentative because, to date, no study has asked participants specifically about their feelings of joint agency. Thus, the primary goal of the present research was to directly examine people's experiences of joint agency. To do so, we employed a sequence production task designed to induce an experience of shared agency, that is, joint agency along with an intact sense of self-agency (Pacherie, 2012). In a series of experiments, we manipulated factors hypothesized to influence joint agency, and employed rating scales that asked participants specifically about their experience of joint agency. Experiment 1 examined Pacherie's (2012) theoretical prediction that people's experience of shared control over a continuous joint action will be stronger when both people are required to coordinate with each other compared to when one person coordinates with the other but not vice versa. Experiment 1 also investigated the influence of social role on the sense of shared control over a continuous action. Because joint agency is thought to include not only a sense of shared control over a continuous action, but also a sense of shared responsibility for action outcomes (Pacherie, 2007), Experiment 2 sought to establish whether the results from Experiment 1 extended to the sense of shared responsibility for a joint outcome. Finally, Experiment 3 followed up an indirect link between action predictability and shared control that was identified in Experiment 1. Specifically, Experiment 3 tested whether sense of shared control is modulated by the predictability of a partner's actions.

CHAPTER 2

THE INFLUENCE OF COORDINATION AND ROLE ON THE SENSE OF SHARED CONTROL

This chapter is based on the journal manuscript:

Bolt, N. K., Poncelet, E. M., Schultz, B. G., Loehr, J. D. (2016). Mutual coordination strengthens the sense of joint agency in cooperative joint action. Manuscript submitted to *Consciousness and Cognition.*

Experiment 1 examined the influence of coordination symmetry and role on people's ratings of shared control. Based on the philosophical and empirical literature reviewed in Chapter 1, we manipulated two factors that we hypothesized would influence the sense of joint agency. First, we manipulated *coordination symmetry* based on Pacherie's (2012) prediction that people are most likely to experience joint agency when coordination relations between them are symmetrical (e.g., when both people in a pair adapt to each other's actions) compared to when they are asymmetrical (e.g., when one person adapts to the other but not vice versa). According to Pacherie, symmetry enhances joint agency by increasing the degree to which (and/or the accuracy with which) people make predictions about the perceptual consequences of each other's actions. This is consistent with empirical evidence linking perceptual information with the experience of agency during joint action (van der Wel, 2015; van der Wel et al., 2012). Second, we manipulated participants' *role* within the joint action based on Pacherie's (2012) prediction that people who act first (leaders) may experience a weaker sense of joint agency. This is consistent with studies showing that people's roles within a joint action influence their ratings of responsibility for a joint action outcome (Dewey & Carr, 2013; Obhi & Hall, 2011).

Experiment 1 employed a sequence production task in which pairs of participants had to coordinate their actions to produce a sequence of tones that matched the pace set by a metronome (see Figure 2.1). Each participant produced half of the tones in the sequence, and each tone was elicited by a single button press. We manipulated coordination symmetry by having participants produce tones either in alternation (ABABABAB, where A and B represent the two partners, respectively) or sequentially (AAAABBBB). The alternating task required symmetrical coordination between partners, because both partners had to adapt the timing of their own actions to the timing of their partner's actions on a turn-by-turn basis. In contrast, the sequential task required asymmetrical coordination between partners because only the second partner had to adapt the timing of their actions to the timing of their partner's actions. We predicted that participants would experience stronger shared control in the alternating compared to the sequential task. Role was determined based on which partner acted first for a given sequence: leaders produce the first tone(s) in the sequence (i.e., partner A as labeled above) and followers produced the subsequent tone(s) (partner B). We hypothesized that the partner who acted first might experience weaker shared control than the partner who acted second.

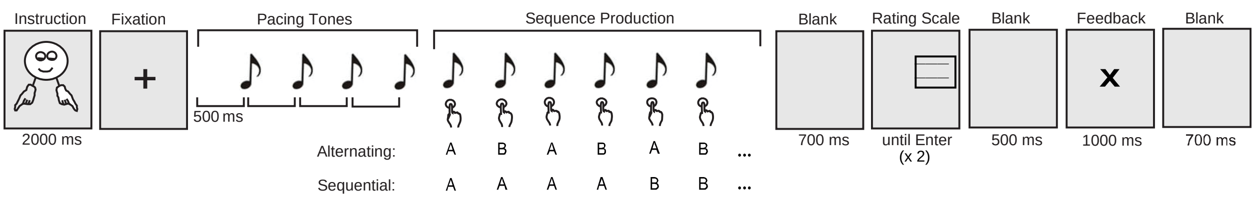

Figure 2.1. Schematic illustration of the sequence production task in Experiment 1. Following instructions and fixation, participants heard a series of isochronous pacing tones (illustrated by eighth note symbols) and then produced a sequence of tones (illustrated by combined button press and eighth note symbols, labeled A and B for the two participants, respectively). After producing the last tone, each member of the pair provided an agency rating. The pair then received feedback indicating whether the sequence they produced matched the pace set by the isochronous tones.

The rating scale we used asked participants to "[r]ate your feelings of control over the timing of the sequence" on a scale ranging from "shared control" to "independent control". We chose this rating scale for several reasons. First, we focused on people's sense of control rather than causal responsibility because the previous research that most strongly suggests that people may experience joint agency was focused on control. Second, we asked participants to rate their control over the timing of the sequence because: a) the task required participants to coordinate their timing to achieve the shared goal of matching the metronome pace, and b) we wanted participants to focus on the timing of the tones rather than the tones themselves, over which we expected them to experience strong and constant self-agency. Third, we used the term "shared control" as the endpoint reflecting joint agency because this terminology is consistent with researchers' and philosophers' descriptions of joint agency (e.g., Dewey et al., 2014; Seemann, 2009), and we used the term "independent control" as the other endpoint to capture the opposite of shared control without implicating agency over the tones themselves.

Method

Participants

Forty-eight University of Saskatchewan students (12 males, mean age = 21.10, *SD* = 3.51) participated in the study in pairs. Thirteen of the pairs had two female partners, 10 pairs were mixed-gender, and one pair had two male partners. Ethical approval was obtained from the institutional review board prior to participant recruitment, and all participants gave informed consent before beginning the study. Participants were compensated with either credit for their introductory psychology course or $10.

Design

Pairs of participants produced sequences of eight tones that matched the pace set by a metronome (i.e., a series of isochronous pacing clicks; see Figure 2.1) in a 2 (task: alternating, sequential) by 2 (role: leader, follower) within-subjects design. In the alternating task, participants produced tones in alternation with each other (i.e., ABABABAB, where A and B refer to each partner, respectively). In the sequential task, one participant produced the first four tones and the other produced the last four tones (AAAABBBB). For half of the sequences, the participant sitting on the left was the leader (i.e., the participant who produced the first tone(s) in the sequence) and for the remaining sequences the participant on the right was the leader.

Apparatus and Materials

Participants sat next to each other on the same side of a table. A computer screen was centered between them and positioned approximately 60 cm from the edge of the table. An Interlink force-sensitive resister (FSR; 3.81 cm^2) was placed directly in front of each participant, approximately 30 cm from the edge of the table. Participants tapped the FSRs with the index finger of their dominant hand. Both participants had visual access to their own and their partner's FSR and finger taps. The FSRs registered participants' taps without providing any auditory feedback. Each tap triggered a 1000 Hz tone (100 ms duration, 10 ms rise/fall time) via a WaveShield connected to an Arduino UNO R3 microcontroller. This setup ensured a very short latency between taps and tones (approximately 3 ms; see Schultz & van Vugt, 2015, for technical details). The Arduinos also sent a signal to the Presentation recording software

(Neurobehavioural Systems, Inc., Albany, CA, USA) each time a tap was registered. Presentation was used to record the taps and to present the remaining auditory and visual stimuli for the experiment, including the four pacing clicks, which were presented in a snare drum timbre. All auditory stimuli were presented through speakers placed on both sides of the computer screen. In addition, number keypads were placed outside each FSR and covered with occluders so that participants could enter their agency ratings but could not see their partner's ratings.

Procedure

The experiment began with two practice blocks, one for the alternating task and one for the sequential task. Each practice block began with two pre-training trials during which the experimenter controlled the presentation of the events that comprised a trial and explained the tasks. The remainder of each practice block consisted of 10 training trials with the timing described in the next paragraph. Participants then completed a test phase consisting of 16 blocks of 5 trials, also with the timing described in the next paragraph. Participants provided agency ratings after every trial in the test blocks only. Blocks alternated between the alternating and sequential tasks, the order of which was held constant through both the training and test phases and was counterbalanced across participants. One member of the pair was the leader for all trials in a given block. We counterbalanced which partner (sitting on the left or right) was the leader on the first test block across participants. The partner who was the leader for the first block became the follower for the second block. The other partner was then leader and follower for the third and fourth blocks, respectively. These four combinations of task and role were repeated four times in the same order to make up the 16 test blocks (and the last two of the four combinations made up the two training blocks). At the beginning of each block, instructions presented on the computer screen indicated which task was to be performed and which participant was to be the leader.

Each trial began with a visual cue to remind participants of the task and roles. The visual cue consisted of a cartoon face with two arms, one of which was colored red to indicate that the person on that side of the table would produce the first tone(s) in the sequence. The word "alternating" or "sequential" appeared above the face. The cue remained on the screen for 2000 ms. A fixation cross then appeared and remained in the center of the screen until the last tone of the sequence was produced. Four pacing clicks were presented at 500 ms intervals beginning 500 ms after the onset of the fixation cross. Participants were instructed to produce the tone sequence while maintaining the pace set by the clicks. After each sequence, participants 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). Participants were instructed to include 0 as the first digit for any ratings less than 10 to prevent their partner from guessing their rating based on the number of keystrokes they entered. Participants were encouraged to take as much time as they needed to complete the ratings. Participants entered their ratings in random order, determined separately for each trial and signaled by which side of the screen the rating scale instructions appeared on first (e.g., the rating scale first appeared on the right side of the screen, signaling the participant on the right to enter their rating, and then switched to the left side of the screen, signaling the participant on the left to enter their rating). After both participants had entered their ratings, feedback indicating whether or not they had correctly matched the metronome pace was presented for 1000 ms in the center of the screen. A green check mark indicated that they had correctly matched the pace and a red "X" indicated that they had not.

Feedback was determined based on whether the average inter-tap interval (ITI) produced by participants fell within a window around the required pace of 500 ms. An adaptive window size was used to ensure that error rates would be similar (approximately 20%) across conditions, preventing a confound between condition and sequence accuracy. The window size was set to 50 ms at the beginning of the experiment (i.e., sequences were considered correct if the average ITI fell within 500 ± 25 ms). After each block, the window size decreased by 10 ms if participants made no errors, stayed the same if they made one error (1 error in 5 trials = 20% error rate), or increased by 10 ms if they made more than one error. The window size was adjusted separately for each combination of task and role, with the exception that the last 5 of the 10 training trials for a given task were used in the first window size adjustment for that task (combined with both roles).

Data Analysis

Performance errors

We analyzed participants' agency ratings only for trials on which they received correct feedback, to avoid potential effects of attribution biases that may come into play when errors are made in a joint task (e.g., Mynatt & Sherman, 1975; Taylor & Doria, 1981). Trials were also removed from the analysis if they contained a sequence production error (participants produced their tones in the wrong order) or a rating error (participants entered their ratings in the wrong order or a participant entered an invalid rating). In total, 0.67% of correct trials were removed due to sequence production errors and an additional 5.21% of correct trials were removed due to rating errors. This left an average of 14.58 agency ratings per participant per condition.

Linear mixed-effects model analysis

We used a linear mixed-effects model analysis to examine the effects of task and role on agency ratings while accounting for shared variance within pairs. We included fixed factors of task (alternating and sequential) and role (leader and follower). We began with a maximal random effects structure (Barr, Levy, Sheepers, & Tily, 2013; Bates, Kliegl, Vasishth, & Baayen, 2015) that included an intercept and slopes for task, role, and their interaction for pairs; an intercept and slopes for task, role, and their interaction for participants; and an intercept for trial. Model fits were estimated using restricted maximum likelihood via the MIXED command in SPSS Version 23. If the model fitting procedure failed to converge, we removed random effects whose covariance was estimated as zero. We then iteratively refined the random effects structure by checking whether the goodness of fit was significantly reduced after the random effect that accounted for the least variance was removed. Specifically, we compared the estimated deviances (-2 log-likelihood; -2LL) using a likelihood ratio test (LRT). This procedure allowed us to remove random effects not supported by the data (Bates et al., 2015). We then tested whether goodness of fit improved by fitting correlation parameters for the remaining variance components and for the residuals (Bates et al., 2015). The final model included an intercept and slopes for role for pairs; an intercept and slopes for task, role, and the task by role interaction for participants; and an intercept for trial. We report F and t tests for fixed effects and post-hoc pairwise comparisons, respectively. Degrees of freedom for these tests were obtained by Satterthwaite approximation.

Results

Figure 2.2 shows the estimated mean agency ratings for each task and role. Participants' mean rating was 39.76 overall (95% CI [33.83, 45.69]), indicating that they tended to experience shared rather than independent control when engaged in a cooperative joint action. However, participants' ratings of control differed depending on both task and role. As Figure 2.2 shows, participants rated their feelings of control as more shared in the alternating task compared to the sequential task, $F(1, 46.90) = 13.10$, $p = .001$. Furthermore, participants rated their feelings of control as more shared when they were the follower compared to the leader, $F(1, 22.64) = 6.10$, p

= .022. Lastly, there was a significant interaction between task and role, $F(1, 39.15) = 7.13$, $p = .010$. Table 2.1 shows the estimated mean differences between roles for each task (and between tasks for each role), along with confidence intervals and standardized effect sizes. As the table shows, the difference in agency ratings between leader and follower was significant in the sequential task but not in the alternating task.[1]

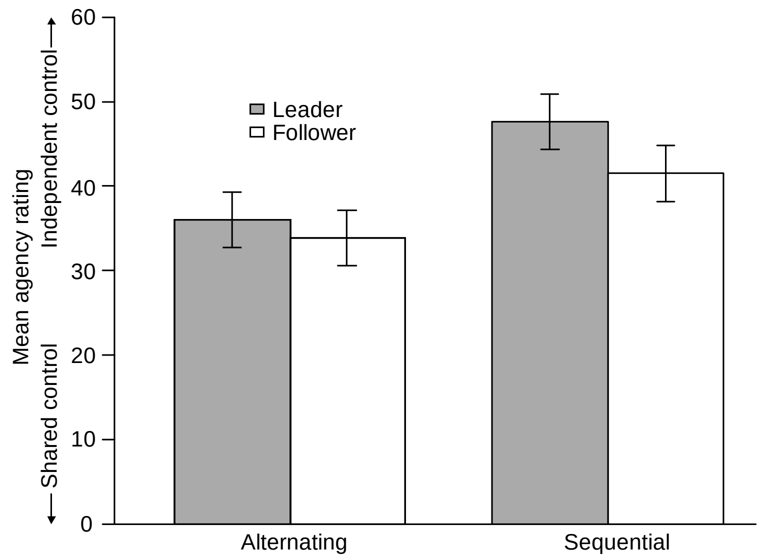

Figure 2.2. Estimated mean ratings of control by task and role for Experiment 1. Error bars represent the standard error of the mean.

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[1]The addition of pair gender as a covariate revealed no significant difference in ratings of control between pairs that consisted of two female partners and pairs that consisted of a female and male partner, $F(1, 21.00) = 0.20$, $p = .66$. Furthermore, the effects of task ($F(1, 44.94) = 14.53$, $p < .001$), role ($F(1, 21.67) = 6.53$, $p = .018$), and the task by role interaction ($F(1, 36.99) = 6.02$, $p = .019$) did not change when pair gender was added to the model. Therefore, pair gender is not considered further here.

Table 2.1

Estimated mean differences in ratings of control between roles for each task.

	Mean diff. [95% CI], Cohen's *d*	*df*	*t*	*p*
Follower vs. Leader [a]				
Alternating	-2.0 [-5.8, 1.7], 0.13	32.5	1.1	.274
Sequential	-6.2 [-9.9, -2.5], 0.41	32.3	3.4	.002*
Alternating vs. Sequential				
Follower	-7.6 [-13.2, -2.0], 0.50	54.5	2.7	.008*
Leader	-11.8 [-17.3, -6.2], 0.77	54.5	4.2	<.001*

[a]Mean differences are defined as the second listed condition subtracted from the first listed condition (e.g., Follower – Leader).

*$p < .05$

Discussion

Experiment 1 examined whether coordination symmetry and role within a joint action influenced people's experience of shared control. The experiment yielded three main findings. First, people experienced a sense of shared control, rather than independent control, when they engaged in a cooperative joint action in which each partner made distinct contributions to a shared goal. Previous studies examining agency in joint action have used rating scales that focused primarily on self- or other-agency (e.g., Dewey & Carr, 2013; Obhi & Hall, 2011) or were ambiguous as to whether they referred to self-agency, joint agency, or a mixture of the two (e.g., Dewey et al., 2014; van der Wel et al., 2012). Experiment 1 is the first study, to our knowledge, that directly asked people about their sense of joint agency. The finding that people experienced a sense of shared control provides empirical support for philosophical accounts that posit that people will experience joint agency when they engage in cooperative joint action (Dokic, 2010; Pacherie, 2012; Seeman, 2009). This finding also supports Dewey et al.'s (2014) inference that people evaluate their sense of control at a group level (i.e., "we did it") and experience joint agency when they continuously coordinate their actions with each other to produce a joint action effect.

Second, Experiment 1 showed that mutual coordination strengthened people's sense of shared control. People experienced more shared control for a task that required both partners to mutually coordinate their actions with each other compared to tasks that required only one partner to coordinate their actions with the other. This finding is consistent with Pacherie's (2012) theoretical prediction that people will experience stronger joint agency when coordination is symmetrical (when both people adapt to each other's actions) compared to asymmetrical (when only one person adapts to the other). A subsequent study showed that this finding can be attributed to differences in objective coordination between tasks (i.e., how well coordinated people's actions were in time; Bolt et al., 2016). People were more objectively coordinated in tasks that required mutual coordination compared to tasks that required asymmetrical coordination, and the difference in shared control between tasks was reduced to non-significant when objective coordination was controlled for statistically. Thus, people felt more shared control when coordination was symmetrical because they were more coordinated in time (Bolt et al., 2016).

Third, leaders in the joint action experienced less shared control compared to followers, but only when the joint action required asymmetrical coordination. This is consistent with Pacherie's prediction that leaders will feel less joint agency than followers because of the salience of their role in the joint action (Pacherie, 2012). However, coordination differences between roles may also explain the differences in shared control we observed. Previous research suggests that leaders coordinate less with their partners than followers. For example, Konvalinka et al. (2014) employed a synchronized finger tapping task in which pairs of participants produced simultaneous taps to match a metronome pace. Spontaneous leader and follower relationships emerged, whereby one person in the pair took the lead in the sequence (leader) whereas the other adapted their own tapping to their partner's timing (slowing down or speeding up to follow their partner's timing; follower). Leaders displayed increased frontal alpha suppression compared to followers, suggesting that leaders spend more resources self-processing rather than adapting to their partner's actions (Konvalinka et al., 2014). Similarly, leaders employ less error correction and focus more on their own tapping performance compared to followers (Fairhurst, Janata, & Keller, 2014). The possibility that leader-follower differences in shared control depend on the degree to which the leader or follower coordinates with their partner is supported by our finding that leader-follower differences in ratings of control depended on the coordination requirements within a given task. Leaders felt less shared control than followers when coordination was asymmetrical, but there was no difference between leaders and followers when coordination was symmetrical. Thus, asymmetrical coordination in which leaders were not required to coordinate with followers yielded larger differences in shared control between roles, whereas symmetrical coordination that required leaders and followers to mutually coordinate with each other yielded no difference in shared control between roles.

Overall, the finding that coordination between partners increased the amount of shared control people felt is consistent with Pacherie's (2012) proposal that joint agency relies on congruence between predicted and actual perceptual consequences of an action. Specifically, better coordination may enhance joint agency by increasing the degree to which people can accurately predict each other's actions. We will return to this relationship in Experiment 3. Before doing so, we next test whether the same factors that affect people's sense of control over a joint action also affect their sense of causal responsibility over a joint outcome.

CHAPTER 3

OUTCOME VALENCE INFLUENCES JOINT RESPONSIBILITY

Experiment 1 established that mutual coordination and role influence people's sense of control over a continuous joint action. However, the sense of joint agency is thought to include not only a sense of *control* over a *continuous action*, but also a sense of *responsibility* over having produced an *outcome* (Pacherie, 2007). Thus, Experiment 2 examined whether mutual coordination and role would likewise influence people's sense of responsibility for a joint action outcome (i.e., whether or not they successfully achieved a joint goal). We predicted that, as in Experiment 1, people would feel more shared responsibility over an outcome produced by mutual coordination, and followers in the joint action would feel more shared responsibility over an outcome than leaders.

Experiment 2 also examined whether the valence of the outcome (i.e., whether the outcome was correct or incorrect) influenced people's sense of shared responsibility. Outcome valence has been shown to influence people's sense of self-agency (Gentsch & Synofzik, 2014; Takahata et al., 2012). For example, people display a self-serving attribution bias, whereby they are more likely to take responsibility for successful outcomes compared to unsuccessful outcomes (Mezulis et al., 2004; Miller & Ross, 1975). During joint action, people display a group-serving bias and attribute successful outcomes to the group rather than individuals (Taylor & Doria, 1981; Zaccaro, Peterson, & Walker, 1987). Furthermore, people may attribute unsuccessful joint outcomes to individuals (including themselves), which seems contradictory to accounts of a self-serving bias. However, when joint success is the goal, a group-serving bias seems to be dominant over a self-serving bias and attributing more responsibility for failure to oneself, and less to other members of the group, may help maintain group cohesion (Taylor, Doria, & Tyler, 1983). Based on these studies, we predicted that the valence of the joint outcome would influence people's sense of joint agency. Specifically, we predicted that people would feel a sense of shared responsibility over successful outcomes, and blame unsuccessful outcomes on individuals (either themselves or their partner).

Experiment 2 employed the same method as Experiment 1, with the following exceptions. First, we revised the rating scale to ask participants to "[r]ate your feeling of responsibility over the outcome" on a scale ranging from "I was responsible for the outcome" to "my partner was responsible for the outcome," with the midpoint indicating "we were both responsible for the outcome”. This scale was based on Obhi and Hall’s (2011) study, in which participants rated their sense of responsibility over producing a single tone on a scale from “completely not responsible” to “entirely responsible”, with the midpoint indicating “we pressed the button at the same time”. The key difference between our scale and the scale used by Obhi and Hall was the that the midpoint on our scale specifically asked about shared responsibility, rather than just asking about unified temporal performance. Second, we provided feedback about the success of the joint outcome after each sequence, prior to agency ratings, to examine how outcome valence influenced people’s sense of responsibility.

Method

The methods were the same as for Experiment 1, with the following exceptions.

Participants

Thirty University of Saskatchewan students (8 males, mean age = 22.7, *SD* = 6.1) participated in the study in pairs. Eight of the pairs had two female partners, 6 pairs were mixed-gender, and one pair had two male partners.

Design

Pairs of participants performed the same sequence production task as in Experiment 1 in a 2 (task: alternating, sequential) by 2 (role: leader, follower) within-subjects design (see Figure 3.1).

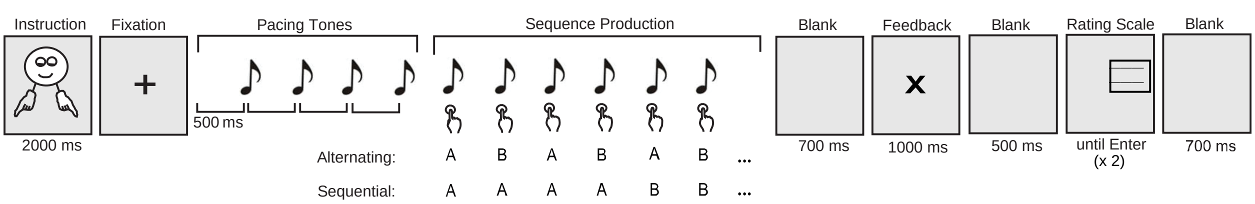


Figure 3.1. Schematic illustration of the sequence production task in Experiment 2. Following instructions and fixation, participants heard a series of isochronous pacing tones (illustrated by eighth note symbols) and then produced a sequence of tones (illustrated by combined button press and eighth note symbols, labeled A and B for the two participants, respectively). After producing the last tone, the pair received feedback indicating whether the sequence they produced matched the pace set by the isochronous tones. Each member of the pair then provided an agency rating.

Procedure

We used the same procedure as in Experiment 1 with two exceptions. First, feedback was presented on the screen after each sequence (and before participants provided their agency ratings). Participants either received a green checkmark (correct) or a red x (incorrect) depending on an adaptive window (see Procedure section of Experiment 1). Second, we used a rating scale that ranged from 01 ("I was responsible for the outcome") to 50 ("we were both responsible for the outcome") to 99 ("my partner was responsible for the outcome").

Data Analysis

Performance errors

Trials were removed from the analysis if they contained a sequence production error (tones were produced in the wrong order) or a rating error (participants entered their ratings in the wrong order or a participant entered an invalid rating). In total, 1.42% of trials were removed due to sequence production errors and an additional 6.59% of trials were removed due to rating errors. This left an average of 18.42 agency ratings per participant per condition.

Linear mixed-effects model analysis

Similar to Experiment 1, we used a linear mixed model analysis to examine the effects of task, role, and outcome on agency ratings while accounting for shared variance within pairs. We included fixed factors of task (alternating and sequential), role (leader and follower), and outcome (correct and incorrect). We began with a maximal random effects structure that included an intercept and slopes for task, role, outcome, and all possible interactions for pairs; an intercept and slopes for task, role, outcome, and all possible interactions for participants; and an intercept for trial. We refined the random effects structure using the same strategy as Experiment 1. The reduced random effects model (Model 3.1) included no random effects and heterogeneous residual covariances.

Results

Figure 3.2 shows the estimated mean agency ratings by task and role for correct and incorrect outcomes, respectively, as estimated in Model 3.1. As the figure shows, agency ratings were similar across tasks and roles. Accordingly, Model 3.1 showed no significant effects of role or task and no two-way or three-way interactions, all $Fs < .70$, all $ps > .40$. We therefore reduced the fixed effects in the model by iteratively removing each non-significant fixed effect (as estimated with full maximum likelihood) and comparing goodness of fit estimates (-2LL). Table

3.1 shows the model comparisons. As shown in the table, model fit did not significantly decrease after removing any of the non-significant fixed effects. Therefore, the final model (Model 3.7) included only the significant fixed effect of outcome, $F(1, 368.59) = 20.82$, $p < .001$. The estimated mean rating for correct outcomes was 49.58 (indicating shared responsibility), whereas the estimated mean rating for incorrect outcomes was 42.47 (indicating more self-responsibility), $d = 0.48$, 95% CI [4.05, 10.19].

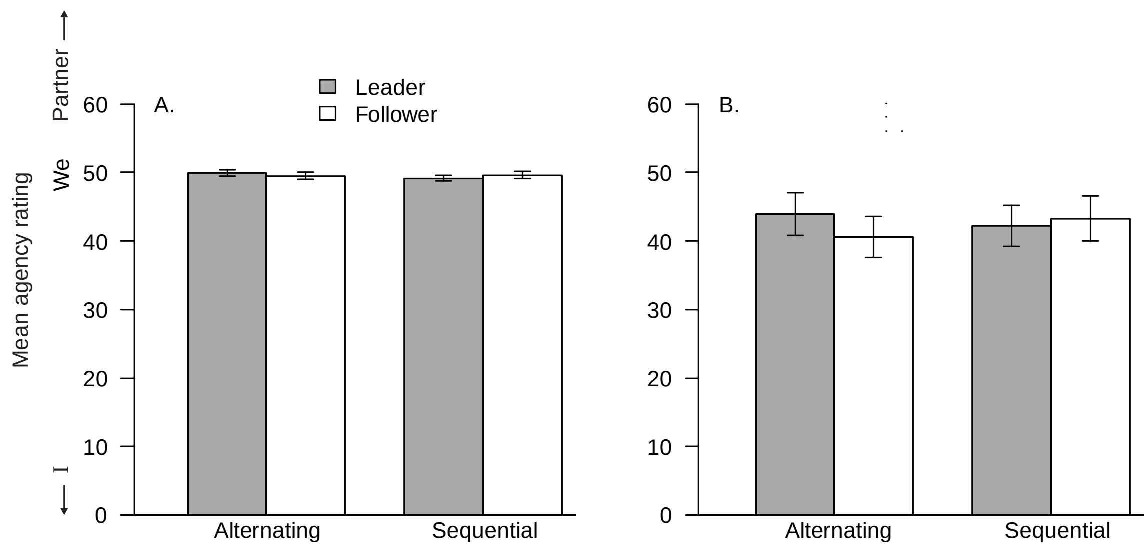


Figure 3.2. Estimated mean ratings of responsibility by task and role for Experiment 2 when the outcome was correct (A) and incorrect (B). Error bars represent the standard error of the mean.

Table 3.1

Model comparisons for the effect of task, role, and feedback on agency ratings.

Model Comparison	Change in *df*	Deviance (-2LL)	χ^2	*p*
Model 3.1		17195.63		
Model 3.2 [vs. 3.1]	1	17195.93	0.30	.58
Model 3.3 [vs. 3.2]	1	17195.99	0.06	.81
Model 3.4 [vs. 3.3]	1	17196.15	0.16	.69
Model 3.5 [vs. 3.4]	1	17197.30	1.15	.28
Model 3.6 [vs. 3.5]	1	17197.30	0.0	1.0
Model 3.7 [vs. 3.6]	1	17197.88	0.58	.45

Note.

T = Task; R = Role; O = Outcome

Model 3.1 = T + R + O + T*R + T*O + R*O + T*R*O

Model 3.2 = T + R + O + T*R + T*O + R*O

Model 3.3 = T + R + O + T*R + R*O

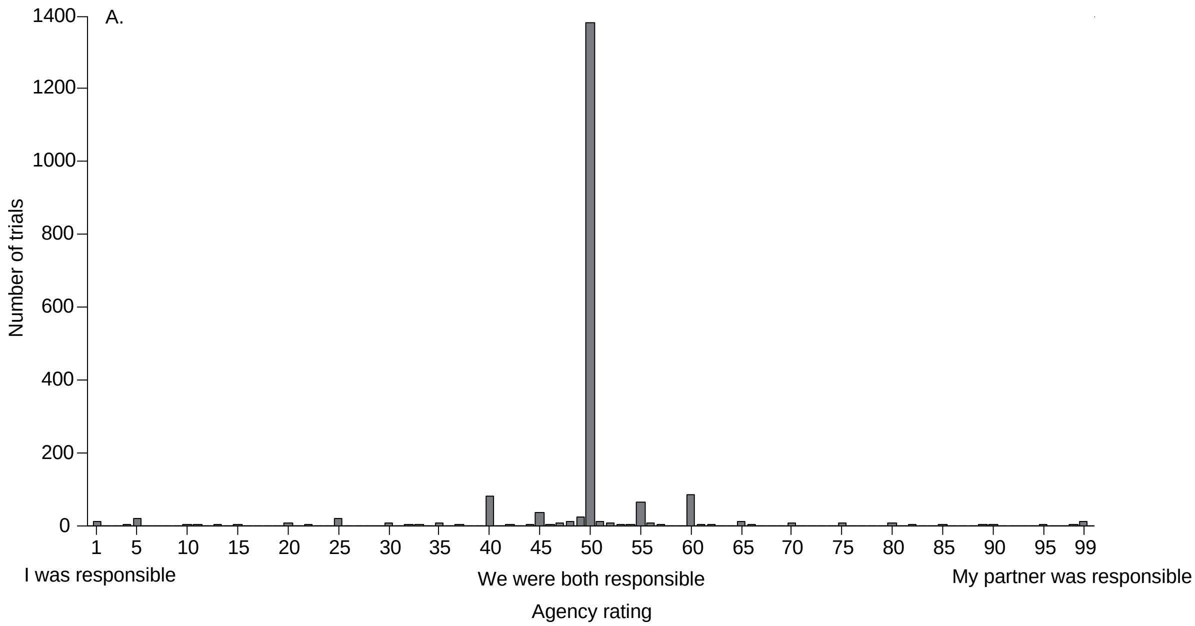
Model 3.4 = T + R + O + T*R

Model 3.5 = T + R + O

Model 3.6 = T + O

Model 3.7 = O

To examine whether participants' ratings were polarized to specific points in the rating scale (cf. Obhi & Hall, 2011), we plotted the frequency of agency ratings at each point along the scale. Figure 3.3 shows the frequency of agency ratings collapsed across task and role for correct and incorrect outcomes. As this figure shows, agency ratings for correct outcomes were almost always exactly 50. In contrast, agency ratings for incorrect outcomes were more varied across the rating scale, with peaks at self-responsibility (1) and shared responsibility (50). This is consistent with the results from the mixed model analysis, which showed lower ratings (closer to 1) on average for incorrect outcomes compared to correct outcomes.



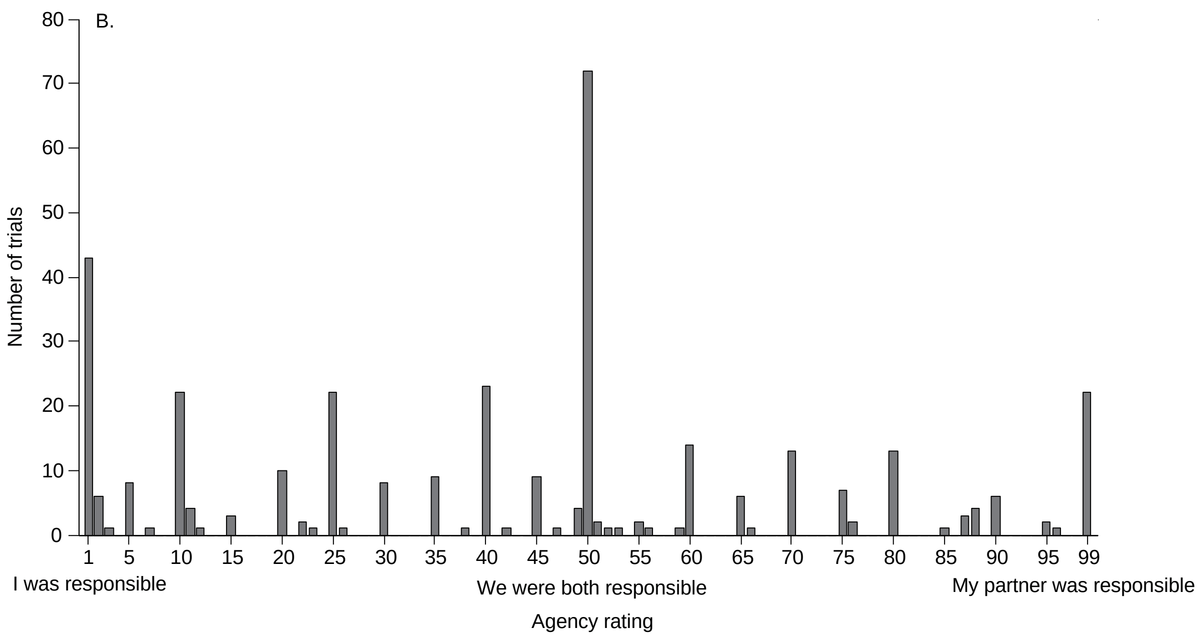


Figure 3.3. The number of trials on which participants selected each point on the rating scale for correct outcomes (A) and incorrect outcomes (B).

Figures 3.4 and 3.5 show the frequency of agency ratings by task and role for correct and incorrect outcomes, respectively. Figure 3.4 shows that agency ratings for correct trials were very similar across combinations of task and role. Figure 3.5 shows that agency ratings for incorrect trials were more varied across combinations of task and role, although the general pattern of peaks at both self- and shared responsibility was consistent across conditions.

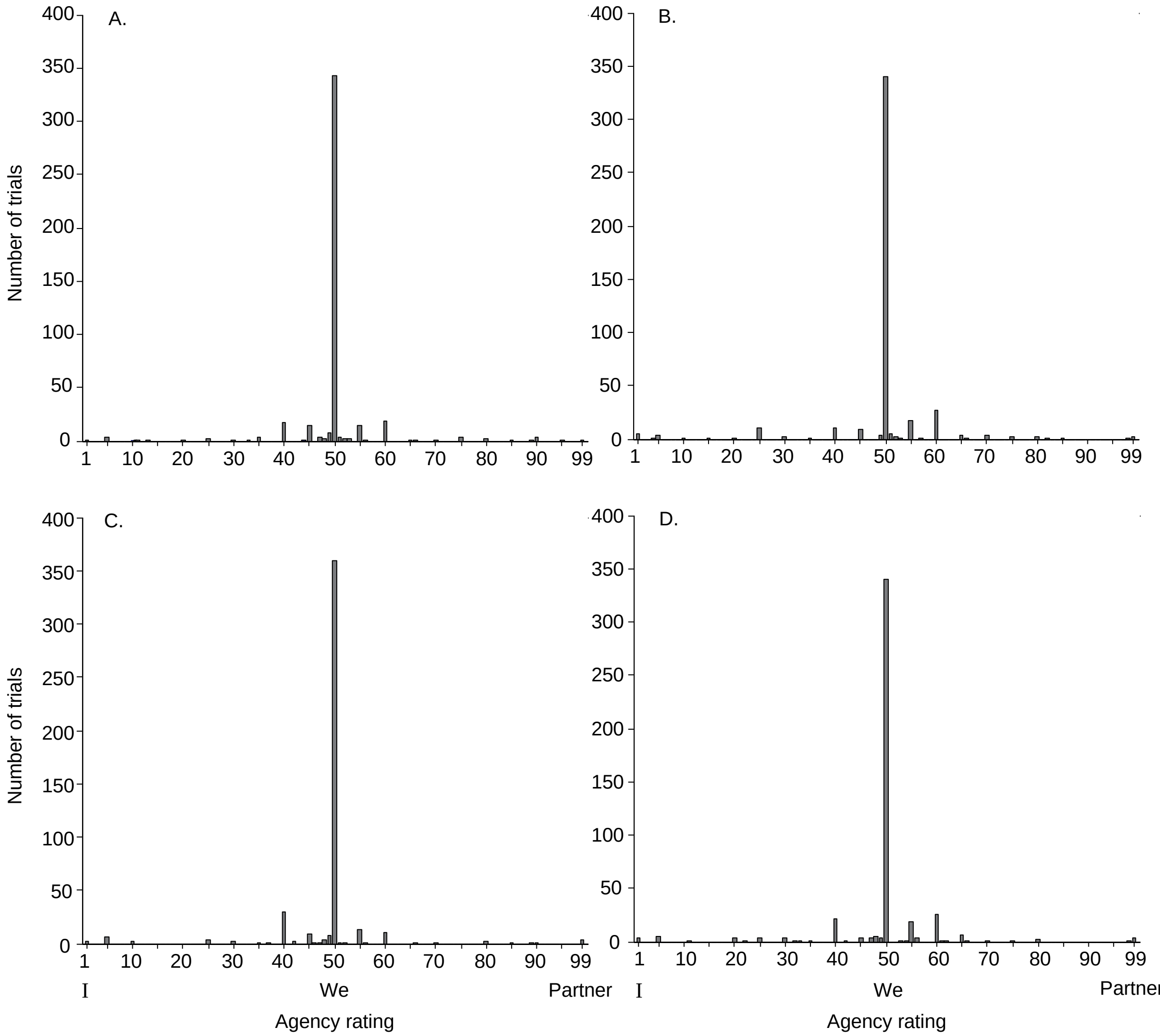


Figure 3.4. The number of trials on which participants selected each point on the rating scale for correct outcomes in each condition: A) alternating leader, B) alternating follower, C) sequential leader, and D) sequential follower.

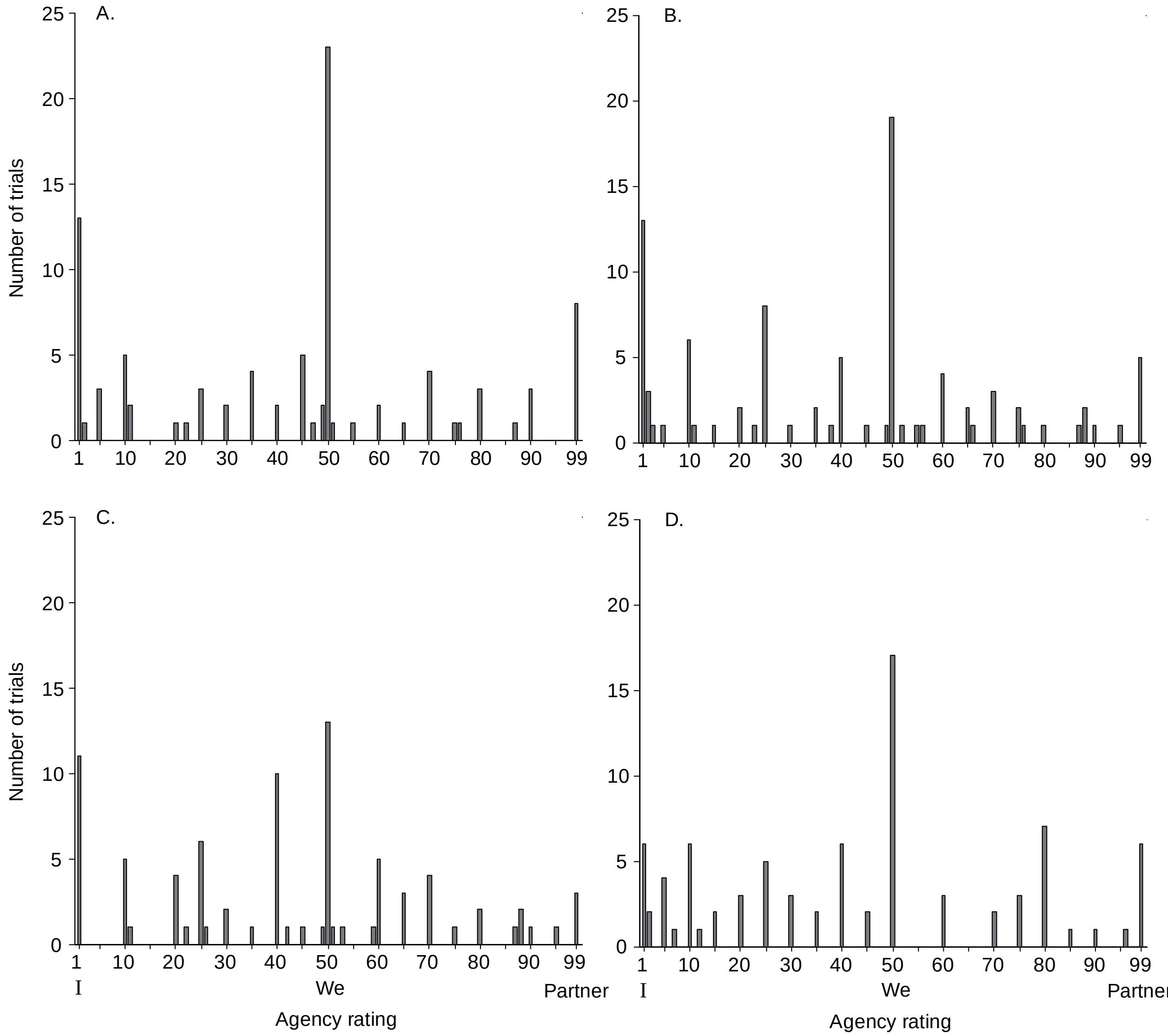


Figure 3.5. The number of trials on which participants selected each point on the rating scale for incorrect outcomes in each condition: A) alternating leader, B) alternating follower, C) sequential leader, and D) sequential follower.

Discussion

Experiment 2 examined whether coordination symmetry, role within a joint action, and outcome valence influenced people's experience of shared responsibility for a joint action outcome. The experiment showed that people's sense of shared responsibility depended primarily on the valence of the outcome. Specifically, people felt more shared responsibility over correct outcomes, and more self-responsibility over incorrect outcomes. This is consistent with previous research showing a group-serving bias, whereby people attribute successful outcomes to the group (Taylor & Doria, 1983). The finding that people also ascribed more self-blame for incorrect compared to correct outcomes is consistent with promoting group cohesion (Taylor & Doria, 1983). People may accept blame for failure to when group success is more important than individual success.

Unlike Experiment 1, Experiment 2 showed that ratings of responsibility did not differ depending on whether people mutually coordinated actions or their role in the joint action. This finding suggests that people's sense of responsibility for a joint outcome may rely on different cues than their sense of control over a continuous joint action. More specifically, this finding suggests that cues to joint agency may be weighted differently depending on which aspect of joint agency people are asked about. In Experiment 2, people may have based their ratings of responsibility on outcome valence because outcome valence was more salient than the factors that influenced action coordination (i.e., coordination symmetry and role). There are two reasons that outcome valence was more salient in Experiment 2 than Experiment 1. First, we specifically asked people about their sense of responsibility over the *outcome*, rather than their sense of control over the *sequence*, thus increasing their attention towards the outcome. Second, we presented the outcome (correct or incorrect feedback) *before* people rated their sense of responsibility, compared to Experiment 1 in which we presented the outcome after people had made their ratings. The finding that cues to joint agency were weighted by salience is consistent with the multifactorial weighting account of self-agency, whereby cues are weighted by their availability, reliability, and/or salience in a given situation (Synofzik et al., 2013).

Obhi and Hall (2011) showed that people's ratings of responsibility over joint outcomes were polarized such that people either attributed responsibility to themselves (self-responsibility) or their partner (other-responsibility) depending on their role in the joint action. This differs from our finding that people almost always felt shared responsibility for correct outcomes and were more varied in the responsibility they felt for incorrect outcomes. There are three important distinctions between our study and Obhi and Hall's study that may explain the differences in findings. First, in Experiment 2, each person produced an equal number of distinct tones to meet a shared goal, whereas in Obhi and Hall's study, two people contributed unequally to produce a single tone. Equal contributions between co-performers are thought to increase the amount of shared responsibility people experience (Pacherie, 2012), leading to more ratings of shared responsibility in Experiment 2 compared to Obhi and Hall. Second, Experiment 2 provided a rating scale that specifically asked about people's sense of shared responsibility, whereas Obhi and Hall included "we pressed the button at the same time" as the midpoint on their scale. The latter focuses on the united temporality of people's actions and does not necessarily imply shared responsibility. Thus, Obhi and Hall's participants could have felt a sense of shared responsibility and yet still provided ratings that polarized toward self or other based on pressing the button at slightly different times. Finally, Experiment 2 provided feedback (correct or incorrect) as the joint outcome, whereas Obhi and Hall provided a tone, which gave no indication of success or failure per se. Therefore, Experiment 2 provided an additional cue to responsibility (outcome valence) that was not present in Obhi and Hall's study.

In the next chapter we return to the sense of control over a continuous action. Experiment 1 showed that factors that increase coordination strengthened the sense of shared control over a continuous action. Coordination is thought to influence the sense of shared control by influencing people's ability to predict each other's actions (Pacherie, 2012). In Experiment 3, we directly examined the link between the predictability of a partner's actions and people's experience of shared control.

CHAPTER 4

THE PREDICTABILITY OF A PARTNER'S ACTIONS MODULATES THE SENSE OF SHARED CONTROL

This chapter is based on the journal manuscript:

Bolt, N. K., & Loehr, J. D. (2016). The predictability of a partner's actions modulates the sense of joint agency. Manuscript submitted to *Cognition*.

Experiment 3 examined whether the predictability of a partner's actions influences the sense of shared control over an action. Like self-agency, the sense of joint agency might rely on predictions about actions and their effects, including predictions about the timing of the action and/or its consequences. However, during cooperative joint action, people make predictions not only about their own actions, but also about their partner's actions and the joint action (Keller et al., in press). Pacherie (2012) proposes that people might use these predictions to inform their sense of joint agency. More specifically, Pacherie hypothesizes that the more accurately people can predict each other's actions, and consequently the joint action, the more joint agency they will feel. For example, when people are better at performing a joint action, they are likely more accurate at making predictions, thus strengthening their sense of joint agency.

Indirect support for Pacherie's (2012) hypothesis comes from empirical findings that people's ratings of control over a joint action are positively correlated with the smoothness of both their own and their partner's movements (van der Wel, 2015) and with pair-level task accuracy (Dewey et al., 2014; van der Wel, Sebanz, & Knoblich, 2012). These findings suggest that people take into account both their own and their partner's action timing during joint action and base their sense of control on how accurately they can predict their own and their partner's actions. However, the rating scales used in these studies were ambiguous as to whether they referred to self-agency, joint agency, or both (Dewey et al., 2014). For example, Dewey et al.'s (2014) scale asked participants to rate "how effective was your joystick at controlling the dot?". Participants felt more control when their partner contributed to the task, suggesting that people may have interpreted the scale as indicating shared control over the dot rather than self control. Indirect support for Pacherie's hypothesis also comes from Experiment 1, which showed that factors that increase coordination between partners increase the strength of shared control (Bolt et al., 2016). Better coordination may enhance joint agency by increasing the accuracy to which people can predict their partner's actions (Pacherie, 2012; Keller, Knoblich, & Repp, 2007; Loehr & Palmer, 2011). Here, we directly test the link between the predictability of a partner's actions and shared control.

Experiment 3 employed the alternating (symmetrical) sequence production task used in the previous two experiments. Participants coordinated their actions with two confederate partners, the timing of whose actions was manipulated so that one partner's actions were highly predictable in time and the other partner's actions were less predictable. Participants rated their sense of control on the same scale as Experiment 1, which asked participants to "[r]ate your feelings of control over the timing of the sequence" on a scale ranging from "shared control" to "independent control". We hypothesized that people would experience stronger joint agency when they coordinated with the more predictable partner.

Method

The methods were the same as for Experiment 1 with the following exceptions.

Participants

Forty-eight University of Saskatchewan Students (17 male, mean age = 19.69, *SD* = 2.18) participated in the study. Ethical approval was obtained from the institutional review board. Participants gave informed consent and were compensated with course credit.

Design

Participants coordinated their actions with confederate partners to produce 8-tone sequences that matched the pace set by a metronome (Figure 4.1). Partner predictability was manipulated within-subjects; each participant was paired with a *high-predictability* partner, whose ITIs were selected from a uniform distribution that ranged from 490-510 ms (i.e., the 500 ms metronome pace ± 10 ms) in 1ms increments, and a *low-predictability* partner, whose ITIs were selected from a uniform distribution from 440-560 ms (500 ± 60 ms).

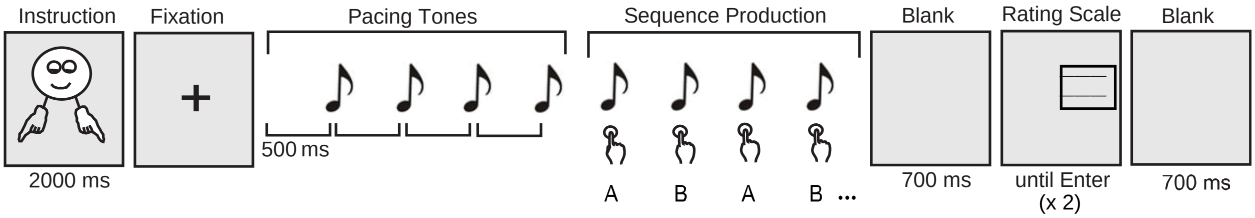


Figure 4.1. Schematic illustration of the sequence production task in Experiment 3. Following instructions and fixation, participants heard a series of isochronous pacing tones (illustrated by eighth note symbols) and then produced a sequence of tones (illustrated by combined button press and eighth note symbols, labeled A and B for the two participants, respectively). After producing the last tone, each partner then provided an agency rating.

Apparatus and Materials

The Arduinos signaled PsychoPy software (Peirce, 2007) when a tap was registered. PsychoPy recorded the taps and presented the remaining stimuli, including the metronome (880 Hz) and confederate (1000 Hz) tones. A 40cm occluder was centered between the FSRs to prevent partners from seeing each other's taps and agency ratings.

Procedure

The confederates and participant arrived at the experiment at approximately the same time. They were instructed that they would coordinate with each other in different pairings and then drew numbers to decide who would sit on the right vs. left. In reality, the participant always drew 1 and was seated on the right, one confederate indicated that they had drawn 2 and was seated on the left, and the other confederate was instructed to leave the room. The two confederates switched places halfway through the experiment. We counterbalanced across participants whether they coordinated with the high- or low-predictability partner first and the assignment of confederates to predictability.

Each half of the experiment began with two trials during which the experimenter explained the task. Partners then performed 5 training trials and 6 blocks of 5 test trials. Both partners provided agency ratings after every test trial. One partner was the leader (produced the first sequence tone) for all trials in a given block. Partners alternated between leader and follower across blocks (including training). We counterbalanced whether the participant was the leader on the first block across participants. At the beginning of each block, instructions presented onscreen indicated which partner was the leader.

Partners were instructed to alternate their actions to produce an 8-tone sequence while maintaining the metronome pace. Confederates produced tapping movements that did not contact the FSR directly. After each sequence, both partners rated their "feelings of control over the timing of the sequence" on a scale from 01 ("shared control") to 99 ("independent control").

After the participant had coordinated with the second confederate, both were told that the coordination phase was complete. They were given the demographics questionnaire and the experimenter left the room ostensibly to give the other participant their questionnaire. Next, the experimenter announced that there were verbal questions to be answered individually, and the confederate was instructed to leave the room first. Participants then completed a debriefing that probed what they thought the purpose of the experiment was, general suspicions, and whether they noticed differences between their partners (Bargh & Chartrand, 2000). One participant guessed the confederate manipulation and was replaced. Most participants (39/48) reported noticing a difference between their partners (e.g., one was better at the task).

Data Analysis

Performance errors

Similar to the previous experiments, trials with rating errors (partners entered their ratings in the wrong order or an invalid rating; 2.2%) were excluded from analysis. Trials with sequence errors were also excluded from analysis. Because the computer produced a confederate tone after each of the participant's taps and/or the last pacing tone, the correct sequence was always produced. Sequence errors were therefore identified by unusually short or long ITIs (3 *SD* above or below the mean ITI across all trials for a given participant; 10.56%), which occurred, for example, if a participant attempted to produce the first sequence tone when the confederate was the leader or paused due to confusion about whose turn it was. Visual inspection of the data also identified 16 trials (0.55%) that contained intervals > 2000 ms, which were excluded before calculating the mean ITIs. Excluding these trials also ensured that we examined people's experience of joint agency independent of attributions of blame for large timing errors.

Linear mixed-effects model analysis

Similar to the previous two experiments, data were analyzed using linear mixed-effects models. We first examined the effect of partner predictability on agency. We began with a maximal random effects structure that included a fixed effect of predictability and a random intercept and slope for predictability. We refined the random effects using the same strategy as the previous two experiments. The final model (Model 4.1) included an intercept and slope for predictability and heterogeneous residual covariances.

Second, we examined the effect of predictability after controlling for the accuracy of the joint performance (*joint accuracy*, defined as the absolute value of the difference between the mean ITI of a given sequence and the required 500 ms ITI), the timing of the participant's actions (*participant timing*, defined as the *SD* of the participant's ITIs [from the preceding tone to the participant's tap]), and the timing of the confederate's tones (*confederate timing*, defined as the *SD* of the confederate's ITIs [from the preceding tone to the confederate's tone]). Because we expected the effect of predictability to be driven by our manipulation of confederate timing, we expected that a) it would remain significant after controlling for differences in joint accuracy and/or participant timing that may have been induced by the manipulation and b) it would be reduced after controlling for confederate timing. We used a step-up strategy (West, Welch, & Galecki, 2015), in which fixed factors were added to the model one at a time and were retained if they significantly increased model fit or removed if they did not. We added the following fixed factors in the following order (Models 4.2-4.7): joint accuracy, joint accuracy by predictability, participant timing, participant timing by predictability, confederate timing, and confederate timing by predictability. To compare models with different fixed effects, we estimated model fit using full maximum likelihood and compared -2LLs using LRT. We re-estimated the effect of predictability after each covariate that significantly improved model fit, using restricted maximum likelihood. We report *F*-tests for fixed effects (degrees of freedom obtained by Satterthwaite approximation), as well as Cohen's *d* and standardized coefficients (β) as measures of effect size for categorical and continuous fixed effects, respectively.

Results

Figure 4.2 shows participants' mean agency ratings by predictability as estimated in Model 4.1. As the figure shows, participants rated their feelings of control as more shared when they coordinated with the high-predictability compared to low-predictability partner. Table 1 (left half) shows the deviance for Model 4.1 and subsequent models. Table 4.1 (right half) shows the effect of predictability (the difference in agency ratings between high- and low-predictability partners), along with its 95% CI, effect size, and *F*-test.

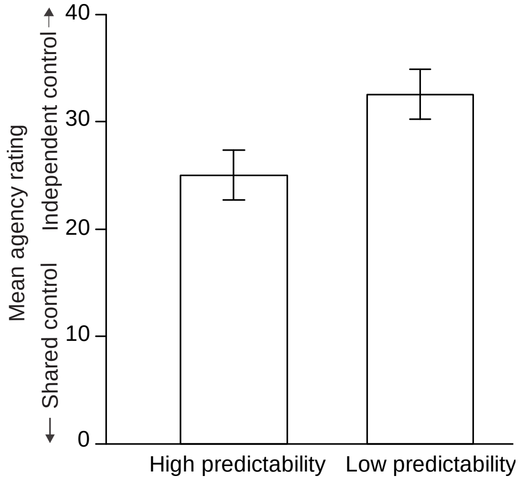


Figure 4.2. Estimated mean agency ratings by partner predictability for Experiment 3. Error bars represent the standard error of the mean.

Table 4.1

Model comparisons for the effect of joint accuracy, participant timing, and confederate timing on agency ratings.

	Model comparisons				Effect of partner predictability			
	Δ *df*	-2LL	χ^2	*p*	Mean diff[a] [95% CI]	*d*	*F* (*df*)	*p*
Model 4.1		21337.43			-7.52 [-12.55, -2.50]	.46	9.07 (1, 46.45)	.004*
Model 4.2 [vs. 4.1]	1	21304.21	33.22	<.001*	-6.93 [-11.90, -1.96]	.42	7.88 (1, 46.59)	.007*
Model 4.3 [vs.4.2]	1	21304.08	0.13	.72				
Model 4.4 [vs. 4.2]	1	21221.26	82.95	<.001*	-6.43 [-11.33, -1.54]	.40	6.99 (1, 46.62)	.01*
Model 4.5 [vs.4.4]	1	21220.14	1.12	.29				
Model 4.6 [vs. 4.4]	1	21215.01	6.25	.01*	-3.44 [-8.83, 1.96]	.21	1.61 (1, 71.89)	.21
Model 4.7 [vs. 4.6]	1	21214.68	0.33	.57				

[a]Mean difference = high-predictability partner minus low-predictability partner.

Note.

P = predictability; JA = joint accuracy; PT = participant timing; CT = confederate timing.

Model 4.1 = P

Model 4.2 = P+JA

Model 4.3 = P + JA + P*JA

Model 4.4 = P + JA + PT

Model 4.5 = P + JA + PT + P*PT

Model 4.6 = P + JA + PT + CT

Model 4.7 = P + JA + PT + CT + P*CT

**p* < .05

Table 4.1 (left) shows that adding joint accuracy, participant timing, and confederate timing significantly improved model fit, whereas adding interactions between these variables and predictability did not. Table 4.1 (right) shows that the effect of predictability was approximately the same size (and significant) after joint accuracy and participant timing were included in the model (Models 4.2 and 4.4), but was smaller in size (and non-significant) when confederate timing was included in the model (Model 4.6).[2]

Figure 4.3 shows the effects of joint accuracy, participant timing, and confederate timing on agency ratings as estimated in Model 4.6. Participants rated their feelings of control as more shared when the joint performance was more accurate (i.e., closer to the metronome pace; Figure 4.3A), $b = .25$, $F(1, 2457.44) = 41.75$, $p < .001$, $\beta = .11$. Participants also rated their feelings of control as more shared when the timing of their own actions was less variable on a given sequence (Figure 4.3B), $b = .17$, $F(1, 2357.55) = 82.11$, $p < .001$, $\beta = .14$. Finally, participants rated their feelings of control as more shared when the timing of their partners' tones was less variable (Figure 4.3C), $b = .11$, $F(1, 1304.59) = 6.26$, $p = .012$, $\beta = .08$.

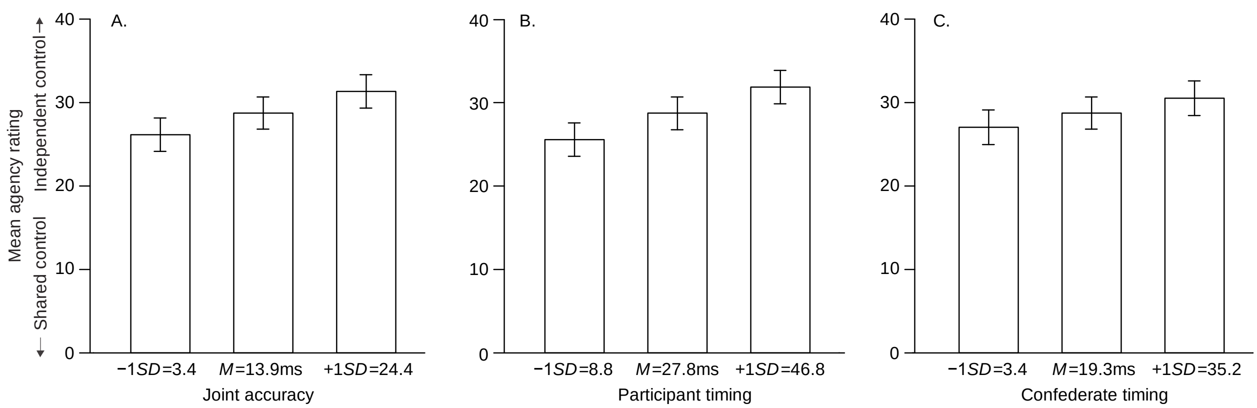


Figure 4.3. Estimated mean agency ratings plotted at mean ±1 *SD* values of A) joint accuracy, B) participant timing, and C) confederate timing. Error bars represent the standard error of the mean.

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[2]The effect of predictability was also reduced and non-significant when only confederate timing was added to Model 4.1 (mean difference = -4.26, 95% CI [-9.78, 1.27], $d = 0.18$, $F(1, 71.08) = 2.36$, $p = .13$).

Discussion

Experiment 3 examined whether the predictability of a partner's actions influences people's experience of shared control during joint action. People reported stronger feelings of shared (as opposed to independent) control over the timing of the sequence when they coordinated with the more predictable partner. This difference remained after statistically controlling for effects of a) overall accuracy of the partners' performance, and b) variability of the participant's action timing, on joint agency. However, the difference was no longer significant after controlling for variability of the partner's action timing. These findings confirm that partner predictability affected shared control independently of its effects on a person's own action timing and the quality of the joint performance.

The finding that people felt increased shared control when their partner's actions were more predictable indicates that people's sense of shared control relies on their ability to accurately predict their partner's actions. This parallels research showing that the sense of self-agency relies on people's ability to accurately predict their own actions (Frith et al., 2000). Moreover, this finding provides empirical support for Pacherie's hypothesis (2012) that people's sense of shared control over a joint action is driven in part by perceptual predictions about co-performers' actions. Thus, during joint action, people also have to take their partners actions into account when determining their sense of joint agency.

Experiment 3 revealed two additional factors that influenced shared control beyond partner predictability. First, more accurate joint performance was associated with stronger feelings of shared control. Although accuracy was implicit in this experiment (i.e., sensed based on the timing of the sequence), rather than explicitly provided through feedback, this finding parallels our results from Experiment 2 whereby people felt more shared responsibility for correct compared to incorrect outcomes. Furthermore, the finding that more accurate joint performance elicited stronger shared control is consistent with previous work showing that pair-level task accuracy is associated with increased feelings of control over a joint action (Dewey et al., 2014; van der Wel et al., 2012). Here, we show that joint accuracy specifically strengthens *joint* agency. Second, reduced variability of a person's own action timing was associated with stronger shared control, indicating that people rely on information about their own actions in addition to their partner's to determine their sense of joint agency. These findings support Pacherie's (2012) hypothesis that joint agency depends on the accuracy of joint- and self-predictions, respectively, in addition to other-predictions.

CHAPTER 5
GENERAL DISCUSSION

Portions of this chapter are based on the following journal manuscripts:

Bolt, N. K., Poncelet, E. M., Schultz, B. G., Loehr, J. D. (2016). Mutual coordination strengthens the sense of joint agency in cooperative joint action. Manuscript submitted to *Consciousness and Cognition.*

Bolt, N. K., & Loehr, J. D. (2016). The predictability of a partner's actions modulates the sense of joint agency. Manuscript submitted to *Cognition*.

Summary of Major Findings

Together, the three experiments presented in this thesis provide direct empirical evidence that people experience a sense of joint agency during joint action. This supports philosophical accounts that predict people will experience joint agency during joint action (Dokic, 2010; Pacherie, 2012; Seeman, 2009), as well as empirical speculation that people evaluate their sense of control at a group level when they engage in joint action (Dewey et al., 2014; van der Wel et al., 2012). Given that the sense of agency consists of both a sense of *control* over a *continuous action* as well as a sense of *causal responsibility* over having produced an *outcome* (Pacherie, 2007), we also show that people experience both a sense of shared control over a continuous joint action (Experiments 1 and 3) and a sense of shared responsibility over a joint action outcome (Experiment 2).

Furthermore, Experiments 1 and 3 provide evidence that the sense of shared control over an action is in part driven by how well people can predict each other's actions (Pacherie, 2012). Experiment 1 provides indirect support for this hypothesis by showing that factors that increase coordination between partners strengthen the sense of shared control. Coordination is thought to enhance joint agency by increasing the degree to which people can make accurate predictions about each other's actions (Pacherie, 2012). In line with this idea, previous research has shown that the better people are able to predict each other's actions, the more coordinated their actions are in time (Keller et al., 2007; Loehr & Palmer, 2011; Zamm et al., 2016). Experiment 1 and subsequent research (Bolt et al., 2016) expand on this to show that the more coordinated people's actions are in time, the stronger their sense of joint agency. Experiment 3 directly tested the link between predictions and shared control by manipulating whether a partner's actions were more or less predictable. We found that people felt more shared control when their partner's actions were more predictable. Thus, our findings are consistent with the hypothesis that congruence between predicted and post-hoc information about another person's actions is used to derive a sense of shared control, much like congruence between predicted and post-hoc information about one's own actions is used to derive a sense of self-agency (Pacherie, 2008). Experiment 3 also showed that the timing of one's own actions and the joint action are also taken into account when determining the sense of shared control: People felt more shared control when the joint outcome was more accurate, and when there was less variability in their own action timing.

Experiment 2 provides evidence that the cues used to determine joint agency receive different weight depending on their salience in the situation. In Experiment 2, people relied on outcome valence, rather than perceptual predictions about a partner's actions, to derive their sense of responsibility over the joint action outcome. Here, cognitive information (i.e., outcome valence) was more salient than it was Experiments 1 and 3 because we specifically asked people about the outcome and presented the outcome before people made their ratings. These findings are consistent with a multifactorial weighting account of self-agency, whereby cues used to inform the sense of self-agency are given more weight depending on their salience in the situation (Synofzik et al., 2013).

The three experiments presented here are the first to empirically investigate the sense of joint agency and provide insight into the factors that influence people's experience of joint agency. In the next section, we discuss the implications of these results for theories of joint agency and joint action.

Implications for Theories of Joint Agency

The findings from the three experiments presented here provide the first direct test of Pacherie's (2012) integrative framework of joint agency. Pacherie states that, like the sense of self-agency, joint agency relies on congruence between predicted and actual action effects. In joint agency, however, people not only have to take into account their own actions, but also their partners' actions and the joint action (Pacherie, 2012). Overall, then, Pacherie theorizes that the sense of joint agency relies on congruence between joint-predictions and effects, which in turn relies on the accuracy of self- and other-predictions at each level of action specification: cognitive, perceptual, and sensorimotor. The experiments presented here provide evidence that the sense of shared control relies on the predictions people make about self-, other-, and joint-action consequences at a perceptual level. Specifically, Experiment 1 provides preliminary evidence that joint agency depends on perceptual predictions during joint action because factors that increase coordination, and thus increase the degree to which people can accurately predict each other's actions (Pacherie, 2012; Keller et al., 2007; Loehr & Palmer, 2011), were shown to increase people's sense of shared control. Experiment 3 directly establishes that joint agency depends on perceptual predictions about the timing of a person's own actions, their partner's actions, and the joint action. These findings expand on previous research that provided indirect support for Pacherie's hypothesis that people's experience of agency during joint action relies on perceptual predictions (van der Wel, 2015; van der Wel et al., 2012).

Our findings also provide a potential avenue to extend Pacherie's (2012) framework. The findings from Experiment 2 suggest that people base their sense of joint agency on the cue that is most salient in the situation, rather than weighting all cues equally. Although perceptual information about each partner's actions was available to the same extent in Experiment 2 as it was in Experiments 1 and 3, people predominantly based their sense of agency on more salient cognitive information about the outcome and less on perceptual information in Experiment 2. Pacherie's framework does not currently provide an explanation for the difference in findings between Experiment 2 and Experiments 1 and 3. Pacherie indicates that cues can come from different levels of action specification (cognitive, perceptual, or sensorimotor), but does not make predictions about how cues at each level will be weighted. Theories of self-agency, such as optimal cue integration theory, have proposed that cues receive different weights depending on their reliability, availability, and salience (Synokzik et al., 2009). Thus, Pacherie's framework could be expanded to include predictions for how cues at different levels of action specification are integrated to inform the sense of joint agency. The findings from our three experiments suggest that, as with self-agency, cues that are more salient will receive more weight in determining the sense of joint agency. Weighting cues based on their salience might be advantageous because it requires less computation, especially for joint agency where predictions and comparisons are made for multiple actions (self, other, and joint actions) at multiple levels of action specification (cognitive, perceptual, and sensorimotor). If a cue is deemed less important, based on its low salience or reliability in the situation, then people may not rely as much on this cue to determine their sense of joint agency.[3] In addition to extending Pacherie's framework of joint agency to include cue weighting and integration at different levels of action specification, theoretical predictions about the sense of joint agency could also address whether self-, other-, and joint-predictions are weighted differently depending on the joint action context and by what mechanisms they are integrated into a coherent experience of joint agency.

Implications for Joint Action

The findings presented here also have implications for theories of joint action, specifically with respect to the internal models involved in joint action. Keller et al. (in press) propose that internal models for self- and other-produced actions run in parallel. Predictions and perceptual effects from individual models are then combined to form a joint internal model (Keller et al., in press). Experiment 1 showed that people felt more joint agency when there was mutual coordination between partners, suggesting that people may predict each other's actions to a greater degree and/or more accurately when they have to mutually coordinate (Pacherie, 2012). Thus, tasks demands (i.e., whether people have to mutually coordinate or not) may influence the degree and/or accuracy with which people predict their partner's actions and integrate their own and their partner's action timing. In addition, Experiment 3 provides evidence that people not only make perceptual predictions about others' actions and incorporate them into their own action planning during joint action (Knoblich & Jordan, 2003; Kourtis et al., 2013; Loehr et al., 2013; Vesper, van der Wel, Knoblich, & Sebanz, 2013); they also rely on those predictions to inform their sense of joint agency. Together, these findings are consistent with Keller et al.'s theory that people integrate individual actions into a joint internal model. Furthermore, these findings suggest that internal models in joint action serve as more than just a mechanism for error correction (van der Steen & Keller, 2013); they also inform people's sense of joint agency.

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[3]For example, if action outcomes were suspected to be unreliable in Experiment 2, people may have instead based their sense of agency on their perception of their how well their partner matched the metronome pace. However, this seems unlikely to have occurred given that the feedback presented in Experiment 2 was veridical and there were no differences in agency ratings depending on task or role. Future research could examine how false feedback influences cue weighting in determining the sense of joint agency.

The association between higher partner predictability on a given trial (i.e., less variability in the partner's action timing) and stronger joint agency in Experiment 3 has implications for research on coordination strategies in joint action. In everyday joint action, "coordination smoother" strategies involve modifying one's own behaviour to facilitate coordination (Vesper, Butterfill, Knoblich, & Sebanz, 2010). One example of a coordination smoother is reducing the temporal variability in one's own actions to enhance interpersonal coordination by making one's actions more predictable (Vesper, van der Wel, Knoblich, & Sebanz, 2011; Vesper, Schmitz, Safra, Sebanz, & Knoblich, 2016). Findings from Experiment 3 indicate that reduced variability of a partner's actions not only facilitates interpersonal coordination but also increases the strength of joint agency. Thus, coordination strategies that utilize predictions to enhance interpersonal coordination may also have the added benefit of strengthening joint agency in joint action.

More broadly, understanding the factors that increase the strength of joint agency has implications for contexts in which people strive to achieve a sense of group cohesion. For example, Overy and Molnar-Szakacs (2009) suggest that "the feeling of being together" is an important component of music therapy. Children with autism spectrum disorder (ASD) may benefit from music therapy because it offers a shared affective experience between co-performers, whereby people are able to extract information about their partner's actions (Overy & Molnar-Szakacs, 2009). Consistent with this hypothesis, the sense of togetherness correlates with how well people coordinate their actions with each other, and children with ASD show less coordination than typically developing children (Marsh, Richardson, & Schmidt, 2009). Similarly, Carron, Shapcott, and Burke (2007) suggest that creating a sense of group identity in team sports contributes to group success. Joint agency may therefore arise in joint action in order to facilitate interpersonal affiliation or group cohesion. Although joint agency and group cohesion appear closely related, further research is needed to investigate how the sense of joint agency influences group cohesion.

Limitations and Future Directions

One potential avenue for future research is to further explore how different leader/follower relationships influence the sense of joint agency. In the experiments presented here, the leader was always the person who produced the first tone(s) in the sequence, whereas the follower produced the subsequent tone(s) in the sequence. Thus, both partners contributed equally to the joint action as well as the joint outcome, and the only difference between roles was who initiated the action. We only found differences in joint agency between leaders and followers in Experiment 1 when coordination requirements differed between tasks, suggesting that leader/follower differences in our paradigm can be explained by coordination differences between the roles. In other studies, leader/follower roles have also included differences in the amount that people contribute to the joint action and in the amount of information people have access to about the joint goal and how to achieve it. For example, a study by Sacheli, Tidoni, Pavone, Aglioti, and Candidi (2013) varied the amount of information leaders and followers had access to about the type of action the pair was required to perform to achieve a joint goal. Leaders were informed of the joint goal and how to achieve it, whereas followers were simply told to coordinate with the leader. This manipulation resulted in diverging action strategies: leaders reduced their action variability to make themselves more predictable, whereas followers imitated the leaders. The tendency for leaders to make their actions more predictable when followers are given less information about the joint action may result in followers feeling more joint agency than leaders because they can better predict their partner's actions. Thus, leader/follower roles might have different effects on the sense of joint agency depending on factors such as how much each co-performer contributes to the joint goal and the information each role has access to about the joint action (cf. Pacherie, 2012).

Future research could also address the specific mechanism through which salience of an outcome influences the sense of joint agency in Experiment 2. We discussed two reasons for why the joint outcome was more salient than perceptual predictions about actions in Experiment 2: a) presenting feedback about the outcome before eliciting agency ratings, and b) asking specifically about people's sense of responsibility for the outcome. Together, these two manipulations may have increased people's attention to the joint outcome. However, it is possible that either manipulation alone may have been enough to increase the salience of outcome valence. A future experiment could examine this possibility by presenting the outcome before the agency rating and asking people about their sense of control over the joint action rather than responsibility for the joint outcome. If the results of this experiment replicate Experiment 2 (i.e., outcome valence influences shared control), this would suggest that presenting a joint outcome before the agency rating increases the salience of outcome valence. If results instead replicate Experiment 1 (i.e., task and role influence shared control), this would suggest that asking specifically about the outcome increases the salience of outcome valence. Future research could also explore how information about an interaction partner can influence the weighting of cues. For example, if a person interacts with a partner that is perceived to be an expert, they might deem perceptual information about their partner's action timing as more reliable, and thus rely more on perceptual information than they would when interacting with a non-expert to determine their sense of joint agency.

Future studies could also examine the relationship between explicit measures of joint agency and implicit measures of agency in joint action. Explicit measures of agency use rating scales to directly probe people's judgments of agency, whereas implicit measures of agency rely on perceptual differences between self- and externally-generated action effects (Dewey & Knoblich, 2014). Examples include intentional binding, in which self-generated actions and effects are perceived as closer together in time than externally-generated actions and effects (Moore et al., 2009), and sensory attenuation, in which the sensory effect of an action (i.e., the loudness of a tone) is suppressed for self- compared to externally-generated events. Studies of agency during joint action have revealed dissociations between explicit and implicit measures. For example, Obhi and Hall (2011) examined both explicit ratings of agency and intentional binding. They found that although partners' explicit ratings of agency were polarized to self- or other-agency, both partners demonstrated similar intentional binding. Other studies have likewise found comparable sensory attenuation between partners for actions produced in interactive contexts (Weiss, Herwig, & Schütz-Bosbach, 2011; Strother, House, & Obhi, 2010). These findings suggest that people may experience joint agency at a pre-reflective level during joint action (Obhi & Hall, 2011). Future studies could examine whether explicit measures of *joint* agency (as opposed to self- or other-agency) are associated with implicit measures of agency for jointly-produced action effects, which could indicate that implicit measures tap into joint agency rather than self-agency when people engage in joint action.

Another intriguing direction for future work involves investigating the neural mechanisms that underlie the sense of joint agency. One proposed mechanism of self-agency is suppression of the N1 event-related potential (ERP; Lange, 2011). The auditory N1 is a negative going ERP component measured at fronto-central regions of the scalp that peaks about 100ms after the onset of an auditory event. The N1 is primarily generated by activity in the auditory cortex and frontal areas (motor cortex, primary motor areas, and the cingulate gyrus; Giard et al., 1994) and is reduced for self-generated compared to externally-generated effects. Loehr (2013) showed that this mechanism may also underlie a self-other distinction in the context of coordinated joint action. In this study, N1 suppression was greater for self-produced tones than for jointly-produced tones. However, jointly-produced tones did show suppression compared to computer-generated tones (Loehr, 2013). Other research provides evidence that N1 suppression occurs for both self- and other-generated tones when people produce their own distinct action effects during interaction (Poonian, McFadyen, Ogden, & Cunnington, 2015). Together, these findings support the idea that N1 suppression underlies a self-other distinction when actions overlap, but may also underlie joint agency when people coordinate to produce their own distinct action effects. Future research could examine whether N1 suppression determines whether people feel a sense of joint agency, in addition to a sense of self-agency, in a joint action context. Additionally, future research could investigate whether N1 suppression differently influences the sense of shared control or the sense of shared responsibility in joint action.

Conclusions

In sum, the series of experiments presented in this thesis confirmed the theoretical prediction that people will experience joint agency when they engage in cooperative joint action. We showed that people experience both a sense of shared control over the joint action as well as a sense of shared responsibility over the joint outcome. Furthermore, we showed that the sense of shared control relies on the predictions people make about self-, other-, and joint-action consequences at a perceptual level, providing support for Pacherie’s (2012) framework of joint agency. The sense of shared responsibility, however, relied on outcome valence rather than action prediction, suggesting that people base their sense of joint agency on cues that are most salient in a given situation. Therefore, we suggest that Pacherie’s framework could be extended to include theoretical predictions about how cues at different levels of action specification are weighted differently depending on their salience.

Processes that facilitate joint action, such as internal models for self-, other-, and jointly-produced action effects (Keller et al., in press) and coordination smoother strategies (Vesper et al., 2010), may also serve to increase the sense of sense of joint agency people feel. In turn, understanding the factors that increase the strength of joint agency has implications for contexts in which people strive to achieve a sense of group cohesion. Although more research is needed to further elucidate the mechanisms that contribute to the experience of joint agency, the three experiments presented here provide the first empirical evidence for how different factors are taken into account and integrated to inform people's experience of joint agency during joint action.

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