



# The sense of agency in joint action: An integrative review

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## Abstract

When people perform joint actions together, their individual actions (e.g., moving one end of a heavy couch) must be coordinated to achieve a collective goal (e.g., moving the couch across the room). Joint actions pose unique challenges for understanding people's sense of agency, because each person engaged in the joint action can have a sense of agency not only at the individual level (a sense that "I moved my end of the couch" or "My partner moved their end of the couch"), but also at the collective level (a sense that "We moved the couch together"). This review surveys research that has examined people's sense of agency in joint action, including explicit judgments of agency, implicit measures of agency, and first-hand accounts of agency in real-world settings. The review provides a comprehensive summary of the factors that influence individual- and collective-level agency in joint action; reveals the progress that has been made toward understanding different forms of collective-level agency in joint action, including the sense that agency is shared among co-actors and the sense that co-actors are acting as a single unit; and synthesizes evidence concerning the relationships between different measures of implicit agency and individual- versus collective-level agency in joint action. The review concludes by highlighting numerous outstanding questions and promising avenues for future research.

**Keywords** Sense of agency · Joint action · Self-agency · Joint agency · Explicit agency · Implicit agency · Review

## Introduction

The *sense of agency* refers to the feeling of generating and controlling actions and their effects (the feeling that "I moved the lamp"). The sense of agency for solo action has been the subject of wide investigation (e.g., Haggard, 2017; Haggard & Eitam, 2015). In recent years, there has been increasing interest in understanding the sense of agency for *joint action*, that is, when two or more people coordinate their actions to produce a change in the environment (Sebanz et al., 2006). Because joint actions are comprised of individual actions (such as lifting and moving one end of a heavy couch) that must be combined to achieve a collective goal (such as moving the couch across the room; see Gallotti & Frith, 2013; Vesper et al., 2010), they pose significant challenges for understanding the sense of agency. Namely, each person engaged in a joint action can have a

sense of agency not only at the individual level (a sense that "I did that" or "You did that"), but also at the collective level (a sense that "We did that together," referred to as joint agency; Pacherie, 2012). A number of studies have now examined individual- and collective-level agency in joint action. The purpose of this review is to synthesize findings from these studies to elucidate what is currently known about agency in joint action and to highlight outstanding questions that remain to be addressed in future research.

Comparing the sense of agency for a joint action, such as moving a couch with a friend, with the sense of agency for a solo action, such as moving a lamp alone, illustrates two critical aspects of agency in joint action that will be highlighted throughout the review. First, joint actions are unique compared to solo actions because they entail multiple possible *subjects* of agency ('who' is the agent of the action; see Himberg et al., 2018, and the "Subjects of agency in joint action" section) and multiple possible *objects* of agency ('what' do they have agency over; see the "Objects of agency in joint action" section). Thus, whereas when moving a lamp alone one has the sense that *I* am moving the lamp, when moving a couch with a friend, one can have a sense that *I* am

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moving the couch, that *you* are moving the couch, or that *we* are moving the couch. Likewise, when moving a lamp alone, one has a sense of agency for the complete action (I am *moving the lamp*), whereas when moving a couch with a friend one can have a sense of agency for the complete joint action (I am *moving the couch*), but one can also have a sense of agency for one's own part of the joint action (I am *moving my end of the couch*) and/or a partner's part of the joint action (I am *moving the other end of the couch*).<sup>1</sup> Second, as these examples illustrate, both the subjects and the objects of agency in joint action can occur at the individual level (*I, you; my action, your action*) or at the collective level (*we; our combined actions*). As will become evident in the sections that follow, considering the literature according to the subjects and objects of agency under investigation in each study yields insight into both the nature of agency for joint action and the factors that impact agency in joint action.

The review is organized as follows. The “Subjects, objects, and aspects of agency in joint action” section details the different subjects and objects of agency in joint action and explains the distinction between explicit judgments of agency and implicit feelings of agency, both of which have been investigated in joint action contexts. The “Explicit judgments of agency” section reviews investigations of explicit agency, highlighting the different combinations of subjects and objects of agency that have been investigated to date and their implications for understanding agency in joint action. The “First-hand accounts of united and external agency” section reviews qualitative studies that include first-hand accounts of agency during real-world joint actions, which complement the investigations of explicit agency presented in the “Explicit judgments of agency” section. The “Implicit agency” section reviews investigations of implicit agency, highlighting several different measures of implicit agency and the relation of each to individual- versus collective-level subjects of agency. The “Conclusions and future directions” section concludes the review by summarizing the conclusions that can be drawn from existing research and highlighting outstanding questions for future research.

## Subjects, objects, and aspects of agency in joint action

Figure 1a outlines the subjects, objects, and aspects of agency that have been investigated in joint action. Overviews of each are presented in the sections that follow.

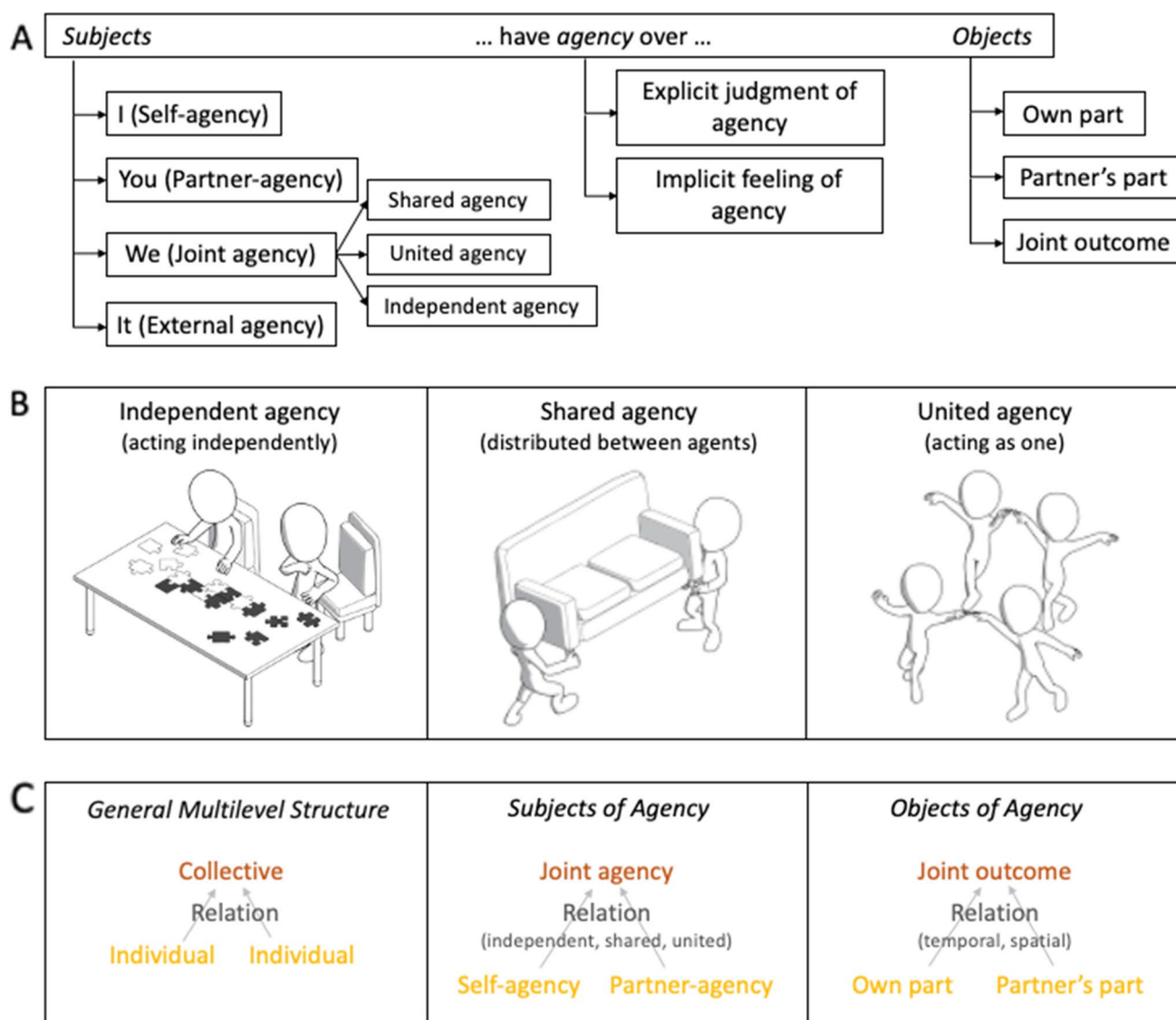
### Subjects of agency in joint action

The left side of Fig. 1a shows four possible subjects of agency for joint action, labeled according to the pronouns people use when describing their sense of agency in joint action (I, You, We, and It; see Himberg et al., 2018) as well as the labels typically used to specify the subject(s) under investigation in a given study (self-agency, partner-agency, joint agency, and external agency). *Self-agency* is the sense that *I* am the agent of an action. *Partner-agency* is the sense that *you* (that is, one's co-actors) are the agent(s) of an action.<sup>2</sup> *Joint agency* is the sense that *we* are the agents of an action. Pacherie's (2012) foundational work on joint agency proposed that it may take two different forms, shared agency or united agency,<sup>3</sup> which are illustrated in Fig. 1b. *Shared agency* is the sense that agency is shared or distributed among people performing the joint action (Pacherie, 2012; Tollefsen, 2014). For example, two people moving a couch together might have a sense that they share control over the movement of the couch. *United agency* is the sense that people engaged in a joint action are acting as a single unit. United agency is thought to involve a blurring of self- and partner-agency (Pacherie, 2012) and to occur primarily in large-scale joint actions such as singing in a choir. Shared and united agency are sometimes contrasted with *independent agency*, that is, a sense that people engaged in a joint action are acting independently to bring about their collective goal (e.g., Bolt et al., 2016; Dell'Anna et al., 2020). For example, two people putting together a puzzle might have a sense that they are each placing pieces independently but nevertheless creating the picture together. Finally, *external agency* is the sense that *it* is the agent of an action, where *it* is an external force or something other than the actors involved in the joint action. Although the sense of external agency occurs relatively rarely in joint action contexts

<sup>1</sup> The sense of agency in solo action is not always as straightforward as implied in this example. For example, people can sometimes have an illusory sense of agency over others' actions when they perform actions in social contexts. Silver et al. (2021) review research on the sense of agency in social contexts ranging from the mere presence of another person to competitive interactions. The current review focuses specifically on the sense of agency in joint actions, i.e., when people coordinate their actions to achieve a shared goal.

<sup>2</sup> Note that all of the research reviewed here examines agency from the perspective of a given individual; no assumption is made that co-actors necessarily share the same sense of agency.

<sup>3</sup> Pacherie (2012) used the term ‘we-agency’ rather than ‘united agency.’ The term united agency is used here to avoid confusion between the form of joint agency (united) and the subject of joint agency (we). Note also that the terms joint agency, shared agency, and we-agency have sometimes been used interchangeably in the literature.



**Fig. 1** **a** Subjects (left), objects (right), and aspects (middle) of agency in joint action. **b** Illustrations of three different forms of joint agency. **c** Multilevel structure of joint action (left) as applied to subjects (middle) and objects (right) of agency for joint action

and has not yet been the subject of systematic investigation, examples arise in contexts such as virtual reality environments (as discussed in the “Explicit judgments of self- and partner-agency for a joint outcome” section), when using a Ouija board (as discussed in the “Explicit judgments of self-, partner-, and joint agency for a joint outcome” section), and during joint music performance (as discussed in the “First-hand accounts of united and external agency” section). Most experimental investigations of agency in joint action have examined self-agency and/or shared agency (as discussed in the “Explicit judgments of agency” and “Implicit agency” sections). United agency has primarily been investigated through qualitative studies of real-world joint action (as discussed in the “First-hand accounts of united and external agency” section).

### Objects of agency in joint action

The right side of Fig. 1a shows three possible objects of agency for joint action. Because people coordinate their individual actions to achieve a collective goal (Gallotti & Frith, 2013; Vesper et al., 2010), they can have a sense of agency for their individual contributions and/or the collective whole. For example, in putting together a puzzle with a partner, the object of agency could be one’s *own part* of the joint action (place the red puzzle pieces), the *partner’s part* of the joint action (place the blue puzzle pieces), or the collective goal (create a visual scene that includes a red barn and blue sky). Evidence that joint actions are represented as individual contributions to a collective goal includes well-established findings that people represent and monitor

their own and their partners' individual parts of the joint action (see Knoblich et al., 2011, for a review) as well as the shared goal of the joint action (e.g., Della Gatta et al., 2017; Loehr et al., 2013; Loehr & Vesper, 2016). Moreover, recent evidence demonstrates that people plan, produce, and perceive individual actions as interrelated contributions to a collective goal (e.g., Begus et al., 2020; Clarke et al., 2019; Kourtis et al., 2019; Milward & Sebanz, 2018; Ramenzoni et al., 2014; Sacheli et al., 2018; Tsai et al., 2011). Example relations that have been investigated to date include temporal relations (e.g., act in synchrony or take turns; Aucouturier & Canonne, 2017; Milward & Sebanz, 2018), spatial relations (e.g., spatial configuration of partners' hands; Kourtis et al., 2019), and harmonic relations (e.g., which chords are produced during joint music performances; Aucouturier & Canonne, 2017; Loehr et al., 2013). The general idea that joint actions entail both individual and collective components, and that the collective level entails specific relations between the individual-level components, is represented schematically in Fig. 1c (left panel). The middle and right panels of Fig. 1c show this multilevel structure applied to the subjects and objects of agency in joint action, respectively. As will be detailed further in the "Explicit judgments of agency" section, this multilevel structure also applies to the different factors that modulate agency in joint action and may be key to understanding their impacts on agency.

In the text that follows, individual contributions to the joint action are usually referred to as *own part* and *partner's part*, and the collective whole is referred to as the *joint outcome*. The term "part" is used deliberately to be inclusive of both actions and action-effects (also referred to as sensory consequences). The term "joint outcome" is used primarily for ease of exposition but also because it is a commonly used shorthand for jointly-produced action-effects. Most research to date has examined agency either for action-effects or for both actions and their effects.

### Aspects of agency

Finally, the middle panel of Fig. 1a shows the distinction between explicit judgments of agency and implicit feelings of agency (Synofzik et al., 2008, 2013). Explicit judgments of agency are measured via rating scales that ask people to report their perceptions of control, causation, or responsibility over actions and their outcomes (Haggard & Tsakiris, 2009; Moore, 2016; Pacherie, 2007, 2008). Explicit judgments are thought to capture higher-level, reflective aspects of agency that are partly informed by cognitive processes in addition to basic sensorimotor processes. In contrast, implicit agency is investigated through measures such as temporal binding (the subjective compression of the perceived time interval between an action and its sensory consequences) and sensory attenuation (a reduction

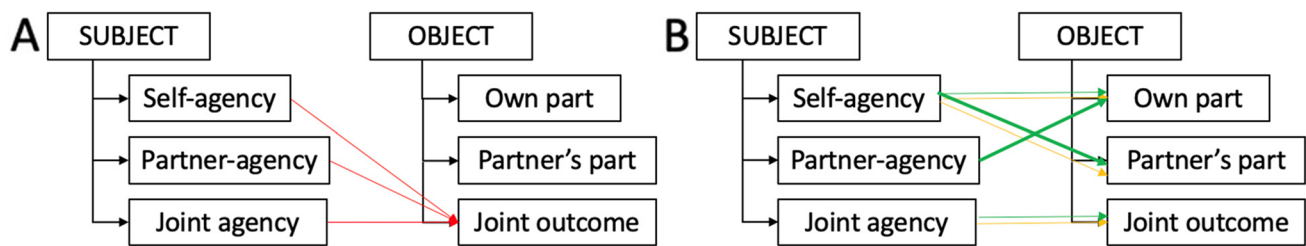
in the perceived intensity of the sensory consequences of actions; see Dewey & Knoblich, 2014, and Haggard & Tsakiris, 2009, for overviews of these measures). Implicit measures are thought to capture low-level, pre-reflective aspects of agency that are grounded in sensorimotor processes. Cue-integration accounts of agency in solo action posit that sensorimotor-level processes captured by implicit measures are integrated with cognitive-level processes to determine explicit judgments of agency (Moore & Fletcher, 2012; Synofzik et al., 2013). In the solo agency literature, research investigating whether implicit and explicit aspects of agency are integrated or independent is ongoing (e.g., Lafleur et al., 2020), as is research investigating the extent to which implicit and explicit measures of agency correlate with each other (see Schwarz et al., 2019, for a recent overview). In the current review, research investigating explicit judgments of agency is discussed in the "Explicit judgments of agency" section and is complemented by first-hand reports of agency discussed in the "First-hand accounts of united and external agency" section. Research investigating implicit measures of agency in joint action is discussed in the "Implicit agency" section.

## Explicit judgments of agency

### Overview

This section reviews studies that examined people's explicit judgments of agency during joint action. It is organized according to the different subjects and objects of agency under investigation in each study. Reviewing the studies from this perspective yields insight into how different factors impact individual-level (self and partner) versus collective-level (joint) agency as well as the type and degree of joint agency people experience during small-scale joint actions.

Figure 2 provides an overview of the different combinations of subjects and objects of agency discussed in each subsection. Figure 2a represents the bulk of research on explicit agency in joint action, which has focused primarily on agency for the *joint outcome* of a joint action. Research examining self- and partner-agency for the joint outcome is considered first (in the "Explicit judgments of self- and partner-agency for a joint outcome" subsection), followed by research that examined joint agency (in the "Explicit judgments of joint agency for a joint outcome" subsection), and finally research that examined both self/partner- and joint agency (in the "Explicit judgments of self-, partner-, and joint agency for a joint outcome" subsection). Figure 2b represents the research reviewed in the "Explicit judgments of agency for individual contributions to a joint action" subsection, which covers the few studies that examined agency for *own and partners' parts* of the joint action. Notably, nearly



**Fig. 2** **a** Subject-object combinations investigated in studies reviewed in the “Explicit judgments of self- and partner-agency for a joint outcome” subsection through to the “Explicit judgments of self-, partner-, and joint agency for a joint outcome” subsection. **b** Subject-

object combinations investigated in studies reviewed in the “Explicit judgments of agency for individual contributions to a joint action” subsection. Arrow colors denote subject-object combinations investigated in different studies (see main text)

all of the studies reviewed in the aforementioned subsections had people rate their sense of *control* during joint action; only a few studies had people rate other facets of explicit agency such as their sense of causation, will, or responsibility (see Moore, 2016; Pacherie, 2008). The “Explicit judgments of togetherness and integration” subsection reviews a handful of studies that had people rate facets of explicit agency that uniquely apply to joint action, including togetherness and integration.

The left half of Table 1 provides an overview of each study reviewed in this section, including the joint action tasks employed and the facets of agency participants rated; which subjects and objects of agency were examined; and key findings. Because one goal of the review was to facilitate across-study comparisons of the effects of different factors on agency in joint action, the right half of Table 1 lists the factors that were examined in each study, describes how they were operationalized, and summarizes their key effects.

### Explicit judgments of self- and partner-agency for a joint outcome

As shown in Table 1, the studies reviewed in this section primarily examined *self-agency* for the *joint outcome* of a joint action; one additionally examined *partner-agency* for the joint outcome.<sup>4</sup> Together, these studies establish that self- and partner-agency can be derived from partners’ combined contributions to the joint action rather than from a person’s individual contributions alone. They also identify boundary conditions for this effect, shed light on a number of factors that influence self-agency during joint action, and begin to

elucidate the neural mechanisms underlying self-agency during joint action.

Three early studies of agency in joint action provided evidence that self-agency is sometimes derived from both partners’ combined contributions to the joint action. Van der Wel et al. (2012) had participants oscillate a pole back and forth between two endpoints by pulling on cords that controlled each end of the pole. People reported similar levels of self-agency when they performed the task jointly with a partner (each controlling one end of the pole) as when they performed the task alone, indicating that self-agency in the joint task was derived from both partners’ combined contributions rather than reduced in accordance with performing only one half of the task. People also reported similar levels of self-agency during initial learning, when they learned either the joint or the solo version of the task, and after the task had been learned, when they switched from performing the task alone to performing the task jointly. Van der Wel (2015) provided further evidence that self-agency is derived from partners’ combined contributions by having partners jointly move a dot to one of two targets, which were positioned such that one partner decided which direction to move and the other had to follow along. The decider and the follower both reported similar levels of self-agency; thus, self-agency was not reduced by the follower’s lack of control over which target was chosen. Furthermore, self-agency correlated with both the smoothness of a person’s own movements *and* with the smoothness of their partner’s movements, indicating that sensorimotor information about one’s own actions and perceptual information about the partner’s actions both influenced self-agency. However, this study also identified a boundary for the effect of partners’ combined contributions on self-agency: When partners’ targets were positioned such that both partners could decide which to move toward, but ultimately one person’s decision had to dominate, the dominant partner reported stronger self-agency than the non-dominant partner. Furthermore, self-agency was correlated with movement smoothness of own and partner’s movements for the dominant partner but not

<sup>4</sup> Three of the studies reviewed in this section did not explicitly specify the object of agency. That is, people were asked to rate their sense of self-agency during the task in general, leaving the object of agency unspecified. However, it seems likely that participants rated their sense of agency over the joint outcome because their individual actions combined to create a single, shared outcome (e.g., the movement of a single dot on-screen).



**Table 1** Studies examining explicit agency

| Subsection   | Authors<br>• Task   | Facet rated                    | Subject             | Object          | Key findings  | Factors examined  | Factors' operationalization  | Factors' key effects   |
|--|---|--------------------------------|---------------------|-----------------|---|---|--|--|
| Explicit judgments of self- and partner-agency for a joint outcome | van der Wel et al. (2012)<br>• Rotate pole back and forth between two targets           | Control                        | • Self              | • Not specified | Self-agency derived from partners' collective contrbs   | Task perf<br>Physical effort  | Target and speed accuracy<br>• Average force<br>• Difference between partners  | Weak corr with self-agency<br>No corr with self-agency   |
|  | van der Wel (2015)<br>• Move dot from centre to one of two targets                      | Control                        | • Self              | • Not specified | Self-agency derived from partners' collective contrbs, except when one partner must dominate  | Task experience<br>Role   | Trial-by-trial changes<br>One partner chooses and the other follows, or both can choose and one dominates  | Self-agency increases with experience<br>Distribution of roles modulates influence of collective contrbs   |
|  | Dewey et al. (2014)<br>• Keep dot centred on moving target                              | Control                        | • Self<br>• Partner | • Joint outcome | Self- and partner-agency derived from partners' collective contrbs, when complementary  | Own sensorimotor info<br>Partner perceptual info<br>Task perf<br>Subjective perf<br>Partner contrbs | Own mvmt smoothness<br>Partner's mvmt smoothness<br>Task completion time<br>Ratings of perf<br>Complementary vs. overlapping                               | Weak corr with self-agency, reduced when following<br>Weak corr with self-agency, except when dominated<br>Weak corr with self-agency<br>Strong corr with self-agency<br>Self- and partner-agency derived from partners' collective contrbs when complementary |
|  | Fribourg et al. (2020)<br>• Virtually move controller from table to one of four spheres | Control                        | • Self              | • Not specified | Self-agency is sensitive to veridical control and to visuomotor coupling even in the absence of veridical control                     | Visuomotor coupling<br>Task perf<br>Veridical control<br>Pre-trial instructions                     | Corr between own mvmt and dot position<br>Corr between partner mvmt and dot position<br>Target accuracy<br>Each partner has 0-100% control over trajectory | Strong corr with self-agency for both types of contrbs<br>Strong corr with partner-agency for complementary contrbs<br>Weak corr with self- and partner-agency<br>Self-agency increases linearly with veridical control  |
| Explicit judgments of joint agency for a joint outcome             | Cho et al. (2020)<br>• Move cursor from centre to one of three targets                  | Control                        | • Self              | • Joint outcome | Cooperation induces IBC of central and temporal theta oscillations  | Visuomotor coupling<br>Personality trait  | Diff between own mvmt and controller trajectory<br>Internal Locus of Control (ILC)   | Self-agency increases with visuomotor coupling<br>Stronger impact of true control on self-agency with higher ILC   |
|  | Bolt et al. (2016)<br>• Produce tone sequences  | Control                        | • Joint (type)      | • Joint outcome | More shared agency for mutual than one-way coordination; mediated by degree of coordination   | Cooperative/competitive context<br>Type of coordination   | Participants believe they are cooperating/competing to move to same/different targets<br>Mutual vs. one-way adaptation                                     | Weaker self-agency in cooperative than competitive context<br>More shared agency for mutual adaptation   |
|  | Bolt and Lochr (2017)<br>• Produce tone sequences                                       | Control                        | • Joint (type)      | • Joint outcome | More shared agency with a predictable partner   | Degree of coordination<br>Role<br>Partner predictability  | Cross-corrs between partners' tap timing<br>Leader produces first sequence tap(s)<br>Partner's timing is more or less predictable                          | Better coordination corr with more shared agency<br>More shared agency for followers, especially in one-way coordination<br>More shared agency with predictable partner  |
|  | Lochr (2018) • Produce tone sequences<br>• Respon-sibility                              | • Control<br>• Respon-sibility | • Joint (type)      | • Joint outcome | More shared agency for more successful joint perf   | Task perf   | Pace accuracy<br>Pace accuracy   | Better perf corr with more shared agency<br>Stronger effect given explicit feedback  |
|  | Dell'Amma et al. (2020)<br>• Sing melodies together                                     | Control                        | • Joint (type)      | • Joint outcome | Shared, not united, agency during duets with temporally distinct contributions  | Task perf<br>Mvmt   | ms-level timing fluctuations and deviations from score durations<br>Performers can or cannot move during performance                                       | Smaller timing deviations corr with more shared agency<br>Moving increases shared agency in pairs who perform less well  |
|  | Shiraishi and Shimada (2021)<br>• Produce tone sequences                                | Control                        | • Joint (type)      | • Joint outcome | Shared agency associated with IBC of theta oscillations between leader's right frontal and fol-lower's right temporo-parietal regions | Type of coordination<br>Role<br>Task perf   | Mutual vs. one-way adaptation<br>Leader produces first sequence tap(s)<br>Percent of intervals falling within the required pace                            | More shared agency for mutual adaptation<br>No difference in shared agency<br>Better perf corr with more shared agency   |

Table 1 (continued)

| Subsection  | Authors<br>•Task  | Facet rated   | Subject                                      | Object                       | Key findings  | Factors examined   | Factors' operationalization   | Factors' key effects   |   |
|---|---|---|--|------------------------------|---|--|---|--|---|
| Explicit judgments of self-, partner-, and joint agency for a joint outcome | Kostrubiec et al. (2018)<br>•Trace Lissajous figures                      | Control   | •Self<br>•Partner<br>•Joint                  | •Joint outcome               | Collective we is subject of agency  | Task experience  | Trial-by-trial changes  | No effect on agency  |   |
|   |   |   |  | •Joint outcome               | Self-agency influenced primarily by individual contribs; joint agency additionally influenced by collective contribs                                  | Role   | Partners make equal or high/low contribs (travel same distance or one travels farther)  | •Self-agency reduced for low-contrib role<br>•Joint agency enhanced for equal-contrib roles                              |   |
|   | Le Bars et al. (2020b)<br>•Move cursor from centre to one of four targets | Control   | •Self<br>•Joint                              | •Joint outcome               | Reward  | Reward   | Partners received equal, contrib-based, or random all-or-none rewards                   | •Joint agency enhanced for equal rewards overall<br>•Rewards affect self- and joint agency differently depending on role |   |
|   |   |   |  | •Joint outcome               | Motor noise   | Motor noise  | Deviations added to cursor mvmt   | Self-agency more impacted by motor noise than joint agency   |   |
| Explicit judgments of agency for individual contributions to a joint action | Le Bars et al. (2020a)<br>•Move cursor from centre to one of four targets | Control   | •Self<br>•Joint                              | •Joint outcome               | Self- and joint agency predominantly influenced by individual contribs and collective goal alignment, respectively                                    | Goal alignment   | Partners share target-reward goals or can have misaligned target or target-reward goals | Joint agency more impacted by goal alignment than self-agency; lowest when both goals can be misaligned                  |   |
|   |   |   |  | •Joint outcome               | Role  | Role   | One partner chooses and the other follows, or both can choose and leader ambiguous      | Leader role boosts self- and joint agency but especially self-agency when both goals can be misaligned                   |   |
|   | Andersen et al. (2019)<br>•Move Ouija board to spell out words            | Pushed, moved                                       | •Self<br>•Partner<br>•External               | •Joint outcome               | Agency attributed to external agent or partner rather than to oneself   | Prior beliefs  | Prior beliefs that Ouija boards can contact spirits                                     | Prior beliefs modulate attribution of agency to external agent vs. partner   |   |
|   |   |   |  | •Joint outcome               | Action-effect prediction  |  | Predictive eye movements  | Reduced prediction might account for reduced self-agency   |   |
|   | Reddish et al. (2020)<br>•Synch cyclical arm mvmts                        | Control, cause, will, unity                         | •Self<br>•Partner                            | •Own part<br>•Partner's part | •People have a sense of mutual agency when they move in synch<br>•Joint agency influenced by perceived coordination but not role or task instructions | Type of coordination   | Mutual vs. one-way adaptation   | Mutual adaptation elicits mutual agency; modulated by role   |   |
|   |   |   |  | •Joint outcome               | Cooperation instructions  | Role   | One partner hears metronome and is instructed to lead; other partner follows            | Leading boosts self-agency over partner's actions; following boosts partner-agency over own actions                      |   |
|   | Christensen et al. (2021)<br>•Play musical duets                          | Control   | •Self<br>•Partner<br>•Joint (type)<br>•Joint | •Joint outcome               | Subjective synch  | Cooperation instructions   | Explicit instructions to work together  | No effect on agency  |   |
|   |   |   |  | •Joint outcome               | Subjective perf   | Subjective synch   | Ratings of synch  | Better synch corr with stronger joint agency   |   |
|   | Explicit judgments of togetherness and integration                        | Noy et al. (2015)<br>•Synch mvmts in 1D mirror game | Togeth-erness                                | •Joint                       | •Joint outcome  | Perceptual distinguishability influences self-agency over own part but not over partner's part or joint agency | Perceptual distinguish-ability  | Duet part (melody vs accompaniment) and distance between parts   | Perceptual distinguishability enhances self-agency over own part                              |
|   |   |   |  |                              | •Joint outcome  | Joint agency linked to mvmt, physiological (heart rate) response   | Coordination  | Synch between tone onsets  | Better coordination corr with more shared agency, regardless of perceptual distinguishability |
|   | Zhou et al. (2021)<br>•Play musical duets or synch tone sequences         | Integration   | •Joint                                       | •Joint outcome               | Shared goal impacts joint agency beyond degree of coordination  | Shared goal  | Shared goal includes rich vs. sparse inter-part relations                               | Joint agency co-occurs with coordinated mvmt and also occurs during periods of little movement                           |   |
|   |   |   |  | •Joint outcome               | Coordination  | Coordination   | Synch between tone onsets   | Stronger joint agency for rich shared goal   |   |
|   |   |   |  |                              | Self-reported factors   | Qualitative interview responses  | Better coordination corr with stronger joint agency                                     | Better coordination corr with stronger joint agency  |   |
|   |   |   |  |                              |   |  |   | Joint agency attributed to song knowledge; performance, task difficulty, enjoyment                                       |   |

for the non-dominant partner, whose ratings correlated with own smoothness but not partner's smoothness.

Dewey et al. (2014) provided evidence that when partners make complementary contributions to a joint action, their combined contributions influence both self- and partner-agency for the joint outcome. In this study, partners kept a dot centered on a moving target. When they made complementary contributions to the dot's movement (each partner controlled one movement direction), self-agency was higher when both partners contributed (both partners' joysticks were turned on) compared to when only one partner contributed (only one's own joystick was turned on). Likewise, people's ratings of their partner's agency were also higher when both partners contributed to the joint outcome compared to when they alone contributed to it. Notably, these findings demonstrate that self-agency increased even though visuomotor coupling between one's individual actions and the joint outcome (that is, the correlation between one's individual joystick movements and the movement of the dot on the screen) necessarily *decreased* when both partners' actions contributed to the joint outcome. This study also identified another boundary for the effect of partners' combined contributions on self-agency: When partners made competing contributions to the dot's movement (their simultaneous movements either doubled or cancelled out the dot's movement), there was no difference in self-agency when both partners contributed to the joint outcome compared to when only one partner contributed to it. Together, findings from these three studies establish that individual-level (self and partner) agency can be derived from partners' combined contributions to a joint task. They also demonstrate that this is not always the case: when one partner dominates or partners compete, self-agency is instead derived from each person's individual contributions to the joint task.

Each of the three studies just described additionally assessed the impact of several other factors on self-agency in joint action. The effects of each factor are summarized in the rightmost columns of Table 1; three sets of findings are highlighted here. First, Dewey et al. (2014) showed that *visuomotor coupling* between the participant's movements and the joint outcome was strongly correlated with self-agency, regardless of whether partners made complementary or competing contributions, and likewise, visuomotor coupling between the partner's movements and the joint outcome was strongly correlated with partner-agency. These findings show that individual-level sensorimotor and perceptual information influenced self- and partner-agency regardless of whether partners' combined contributions also impacted agency. Second, Dewey et al. (2014) showed that pairs' *task performance* was weakly correlated with both self- and partner-agency, and accounted for little variance after controlling for visuomotor coupling. Likewise, van der Wel et al. (2012) and van der Wel (2015) both showed that

pairs' task performance was weakly and somewhat inconsistently correlated with self-agency. These findings contrast with a relatively strong and consistent effect of task performance on *joint* agency, which is reviewed in the "Explicit judgments of joint agency for a joint outcome" subsection. Third, van der Wel et al. (2012) showed that the amount of *physical effort* exerted by the pair, as well as the distribution of the physical effort between members of the pair, did not correlate with self-agency. These three sets of findings are noteworthy not only because of the effects (or lack of effects) of each factor on self-agency. They are also noteworthy because they illustrate a key theme that will be revisited elsewhere in this review: that considering the effects of different factors from the perspective of the multilevel nature of joint action (illustrated in Fig. 1c) may be key to understanding their differential impacts on agency. That is, the three highlighted sets of findings show that self-agency in joint action is differentially influenced by *individual-level factors* (e.g., visuomotor coupling between one's own movements and the joint outcome), *collective-level factors* (e.g., the pair's task performance), and *the relation between partners* (e.g., the distribution of force between partners, which, notably, van der Wel et al., 2012, examined separately from partners' collective-level average force). As becomes evident in subsequent subsections, joint agency is likewise differentially influenced by individual- versus collective-level factors.

Two recent studies further investigated people's sense of self-agency in joint action. Fribourg et al. (2020) shed further light on the factors that influence self-agency by having participants perform joint actions within a virtual reality environment. Specifically, partners virtually moved a pointer from a table to a target, and the pointer's movement was determined by a weighted combination of the two participants' actual movements, such that one partner's movement was weighted 100% (full control), 75%, 50%, 25%, or 0%, and vice versa. Self-agency increased linearly with participants' true control over the pointer. Self-agency was also stronger when the target was specified in advance, in which case people even experienced a degree of self-agency when they had no true control over the pointer's movement. Because visuomotor coupling between the participants' movements and the pointer's trajectory was higher when the target was pre-specified, and stronger visuomotor coupling itself was correlated with stronger self-agency, these findings indicate that self-agency is sensitive to visuomotor coupling even in the absence of true control. This study also showed that people with a stronger internal locus of control (a personality trait that captures the tendency to believe that life events are caused primarily by one's own actions) were more sensitive to changes in true control. Finally, this study provides a first example of external agency during joint action: Among a handful of first-hand accounts of people's experiences during the joint task, one participant reported



having a sense of external agency on some trials: “I had the impression that sometimes no one controlled my movement and that I was actually watching a video” (p. 11).

Finally, Cho et al. (2020) investigated the neural mechanisms underlying self-agency in joint action. Their study compared self-agency when people believed they were cooperating to achieve a shared goal versus competing to achieve different goals. Participants’ brain activity was recorded using electroencephalography (EEG) while they moved a cursor to one of three targets. Participants were told that they would sometimes cooperate with their partners (move to the same target) or compete with their partners (each try to move to different targets); however, on critical trials they were given the same target and merely believed they were cooperating or competing. Cooperative trials elicited reduced self-agency accompanied by stronger inter-brain coupling (IBC) between partners’ neural oscillations in the theta band over temporal and central regions, which are known to be involved in social information processing and interpersonal coordination. These findings provide initial evidence that IBC could be linked to self-agency during cooperative joint action.

In sum, the studies reviewed in this subsection demonstrate that individual-level (self and partner) agency is sometimes derived from partners’ combined contributions to a joint action; that individual- and collective-level factors as well as the relation between partners influence self-agency during joint action; and that IBC may be a promising neural mechanism underlying self-agency during joint action. Next, the review turns to studies that examined collective-level (joint) agency for the joint outcome of a joint action.

### Explicit judgments of joint agency for a joint outcome

As shown in Table 1, the studies reviewed in this subsection examined *joint agency* for the *joint outcome* of a joint action. The studies reviewed in this subsection had people rate the *type* of control they experienced, using rating scales whose endpoints ranged from one type of joint agency (usually shared) to another type of joint agency (usually independent). This contrasts with the studies reviewed in the “Explicit judgments of self- and partner-agency for a joint outcome” and “Explicit judgments of self-, partner-, and joint agency for a joint outcome” subsections, which had people rate their *degree* of control using scales that ranged from no control to complete control. The studies reviewed in the current subsection establish that people have a sense of *shared agency* when they perform joint actions in pairs. They also shed light on several factors that promote a sense of shared agency and begin to examine the neural mechanisms that underlie shared agency.

One early study of joint agency for a joint outcome provided evidence that both the type and degree of coordination

between partners modulates joint agency. Bolt et al. (2016) had partners produce tone sequences that matched a metronome pace and then rate their sense of shared versus independent control over the sequence timing. Partners either engaged in mutual coordination, i.e., they tapped in alternation with each other and thus both partners adapted to each other’s action timing, or engaged in one-way coordination, i.e., one partner produced all of their tones first and thus only the partner who followed could adapt their action timing. People reported more shared agency when they engaged in mutual coordination compared to one-way coordination; critically, this difference was statistically accounted for by the greater degree of coordination partners achieved in the mutual coordination task. Furthermore, followers (who acted second) reported more shared agency than leaders (who acted first), especially during one-way coordination in which only the follower had to adapt to the leader’s action timing and not vice versa. Taken together, these findings show that people experience more shared agency the more they are required and able to adapt to their partner’s action timing.

Subsequent studies using a similar paradigm revealed that, similarly to how self-agency is linked to both one’s own and a partner’s contributions to the joint action, joint agency is also linked to both one’s own and a partner’s contributions. Bolt and Loehr (2017) showed that people report more shared agency when they coordinate with a partner whose timing is more rather than less predictable, and that joint agency is correlated with the variability of both the participant’s and the partner’s action timing. In a similar vein, Loehr (2018) showed that people report more shared agency when the pair’s task performance is more accurate, and that both partners’ individual accuracy contributes to the effect of pair-level performance on joint agency. Loehr (2018) also showed that although pairs’ task performance influences joint agency even in the absence of explicit performance feedback, its effect is enhanced when explicit feedback is provided. This finding aligns with evidence from the solo action literature that cues to agency are weighted partly by their salience in a given context (e.g., Moore & Fletcher, 2012). A question for future research is whether differences in the relative salience of joint task performance could account for differences in its impact across studies (i.e., the relatively small impact of pairs’ task performance on self-agency as reviewed in the “Explicit judgments of self- and partner-agency for a joint outcome” subsection). Finally, Loehr (2018) reported an additional experiment in which participants rated their sense of responsibility for the joint outcome. People reported a more shared sense of responsibility for more successful joint performances, demonstrating that joint task performance impacts joint agency whether it is measured as shared relative to individual responsibility or shared relative to independent control.

Dell'Anna et al. (2020) examined joint agency under more ecologically valid conditions by using a musical duet task in which partners produced melodies together by singing notes in alternation with each other. Critically, their study also used an expanded rating scale that included not only independent and shared agency but also united agency. Furthermore, rather than providing ratings after each duet performance, participants first completed all performances, then watched a video of each performance while providing continuous ratings of performance quality, and then provided a rating of their sense of joint agency for the “moments with the highest quality assessment” during that performance (p. 5). Overall, people reported a sense of shared rather than united agency during peak moments of duet singing. This finding is noteworthy because collective music performance is a joint action in which united agency is predicted to, and does, arise (Pacherie, 2012; “First-hand accounts of united and external agency” section). This study therefore provides a critical starting point for further research into which characteristics of group music performance elicit shared versus united agency. For example, did performers have a sense of shared rather than united agency because of the relatively small group size, because they sang notes in alternation rather than in synchrony, or because they performed in an unusual (laboratory) venue? Dell'Anna et al.'s (2020) findings additionally confirmed that people report more shared agency for more successful joint performances, in this case regardless of whether joint performance was measured in terms of millisecond-level timing fluctuations or deviations from the interval durations notated in the musical score. They also showed that pairs who performed less well overall reported more shared agency when they were allowed to move during the performance compared to when they were not allowed to move.

Finally, Shiraishi and Shimada (2021) investigated the neural underpinnings of joint agency. Partners performed the same mutual and one-way coordination tasks as employed by Bolt et al. (2016), and inter-brain coordination (IBC) between their neural oscillations was measured using EEG. People reported more shared agency when they engaged in mutual compared to one-way coordination, in line with Bolt et al.'s (2016) findings; however, in this study there was no difference in joint agency between leaders and followers. IBC between theta oscillations in the leader's right frontal region and the follower's right temporoparietal region was greater when partners engaged in mutual compared to one-way coordination. Furthermore, stronger IBC between these regions was associated with more shared agency overall, and the strength of IBC statistically accounted for the difference in joint agency between the mutual and one-way coordination tasks. These findings provide initial evidence that shared agency may be underpinned by IBC between brain areas responsible for movement planning and control in the leader of a joint

action, and social information processing in the follower of the joint action, respectively. The findings also align with broader research investigating the brain activity that underlies coordination between leaders and followers during joint action (see Bolt & Loehr, 2021b, for a recent review).

In sum, the studies reviewed in this subsection establish that people have a sense of shared agency when they perform joint actions in pairs and demonstrate that a variety of factors influence joint agency, including individual-level factors (e.g., the predictability of a partner's actions), collective-level factors (e.g., joint task performance, behavioral coordination, and inter-brain coordination), and the relation between partners (e.g., leader vs. follower roles).

### Explicit judgments of self-, partner-, and joint agency for a joint outcome

As shown in Table 1, the studies reviewed in this subsection examined both self-agency (and, in one case, partner-agency) and joint agency for a joint outcome. Note that each of these studies probed the *degree* of agency people experienced. Together, the studies reviewed in this subsection provide insight into the relationship between individual- and collective-level agency as well as the factors that influence agency at each level.

Kostrubiec et al. (2018) simultaneously examined self-, partner-, and joint agency. In this study, partners co-produced a Lissajous figure, which is a visual trace of the movement of a dot whose motion is determined by partners' combined joystick oscillations. This task is relatively difficult because one partner's oscillations cause the dot to move horizontally and the other's vertically, and partners were instructed to trace a circle, which required them to oscillate their joysticks at the same speed and amplitude, but at a lag of a quarter cycle. Participants were asked to rate, on separate rating scales, the degree to which they, their partner, and both they and their partner were in control of the Lissajous figure. People rated their sense of self- and partner-agency as approximately equal, and halfway between no control and full control (mean ratings of 56 and 52, respectively, on a scale of 1–100). They rated their sense of joint agency as significantly higher than either self- or partner-agency (mean rating of ~80 on a scale of 1–100). These findings indicate, first, that people experienced the collective (*we*) to be the subject of agency in this joint action, with agency distributed equally between individual members of the collective.<sup>5</sup> Second,

<sup>5</sup> This conclusion is further supported by the finding that many participants chose to perform the task with both partners' eyes open even when given the option to complete it with one partner's eyes closed, which makes the task considerably easier. According to post-experiment interviews, participants made this choice because they experienced the task to be a collective one.

people perceived the collective to have high but not full agency over the joint outcome. These findings provide initial evidence that self- and partner-agency are dissociable from joint agency, and furthermore, that the strength of joint agency is not necessarily the sum of individual-level agencies but may instead obtain uniquely at the collective level.<sup>6</sup> Here, the strength of joint agency was likely influenced by the relative difficulty of the task, in line with evidence, presented next, that other task-related factors modulate the strength of joint agency. Finally, Kostrubiec et al. (2018) also reported that neither self-, partner-, nor joint agency changed with practice, even though performance did improve with practice. This aligns with the relatively small effects of practice on self-agency reported by van der Wel et al. (2012).

Two studies by Le Bars and colleagues simultaneously examined self-agency and joint agency, and provide evidence that they are differentially influenced by individual-level factors and the relation between partners, respectively. In Le Bars et al.'s (2020b) study, partners moved a cursor to one of four targets. They either made equal contributions to the task (both partners traveled equal distances) or low- and high-contributions (one partner traveled farther than the other). During each trial, a small or large degree of motor noise was added to partners' key-presses. After each trial, partners received rewards that were either equally shared between them, "fairly" distributed in accordance with partners' individual key-press contributions, or distributed such that one randomly chosen partner received the complete reward. Self-agency was more strongly influenced by individual-level factors, including motor noise (which had twice the effect on self-agency compared to joint agency), each person's individual contribution to the joint task (performing the low-contribution role reduced self-agency compared to equal- and high-contribution roles), and individualized rewards (fairly distributed rewards magnified differences between low- and high-contribution roles for self-agency but not joint agency). In contrast, joint agency was consistently enhanced by a *balanced* relation between partners: joint agency was enhanced for equal- compared to low- and high-contribution roles, and receiving equal rewards enhanced joint agency for both the low- and high-contribution roles. In Le Bars et al.'s (2020a) study, partners again moved a cursor to one of four targets. Now, rewards were placed on some targets and were manipulated such that partners' goals could be aligned with respect to both target and reward (only one target provided a reward), could mismatch with respect

to target but not reward (two targets each provided equal rewards), or could mismatch with respect to both target and reward (two targets provided different rewards to each partner). Furthermore, targets were positioned such that one partner decided which target to move to and the other had to follow along, or both partners could decide and leader/follower roles were therefore ambiguous. Self-agency was again more strongly influenced by individual-level factors (motor noise and holding the role of leader had a stronger impact on self- than joint agency), whereas joint agency was more strongly influenced by the relation between partners (joint agency was reduced when partners' target and reward goals could misalign). Together, these studies provide initial evidence that individual-level factors more strongly influence self-agency, whereas the relation between partners (whether balanced contributions or rewards, or a match versus mismatch of partners' goals) more strongly impacts joint agency.

A final study to review in this subsection examined self-, partner-, and *external* agency during joint action. Andersen et al. (2019) examined agency during a Ouija board session, in which people guided the movement of a planchette around a lettered board to spell out messages. Participants were recruited at a Ouija board conference, and thus many believed that the Ouija board could be used to spell out messages from a spiritual entity. Participants' eye movements were tracked while they either used the board as they normally would (i.e., they posed questions and used the board to spell out answers) or spelled out a pre-determined word. At the end of the experiment, participants rated their sense of self- and partner-agency as well as their sense of external agency (whether they felt the planchette "moved on its own") in the "normal use" condition. People reported a very weak sense of self-agency, regardless of their prior beliefs about the Ouija board. Those who believed the Ouija board could be used to contact spiritual entities reported a strong sense of external agency, that is, that the planchette had moved on its own, that they had contacted an external entity during the experiment, and that neither they nor their partner had deliberately moved the planchette. In contrast, those who did not believe the Ouija board could be used to contact an external entity reported a moderate sense of either partner- or external agency. Participants' eye-movement data revealed that they were less likely to make predictive eye movements toward upcoming letters in the normal use condition compared to the pre-determined word condition. Because people's ability to predict the sensory consequences of their actions is a key driver of self-agency in solo action (see, e.g., Synofzik et al., 2013), reduced prediction in the normal use condition could potentially account for people's weak sense of self-agency in that condition. Thus, this study demonstrates that people can experience a strong sense of external agency during joint action, and provides initial

<sup>6</sup> Hart et al. (2014; Fig. 5) provide a compelling illustration of how a collective (movement) outcome can obtain uniquely at the collective level instead of reflecting the average across individuals or one dominant individual.

evidence that low-level sensorimotor cues might reduce self-agency and thereby create the necessary conditions for higher-level prior beliefs to influence attribution of agency to a partner or an external agent.

In sum, the studies reviewed in this subsection provide evidence that individual-level (self and partner) agency is dissociable from collective-level (joint) agency and that agency at each level is differentially influenced by individual-level factors versus the relation between partners. They also provide initial evidence regarding factors that might promote external agency over self-, partner-, or joint agency.

### Explicit judgments of agency for individual contributions to a joint action

Nearly all of the studies reviewed so far investigated people's sense of agency for the *joint outcome* of a joint action. The studies reviewed next investigated agency for the *individual parts* of the joint action. Here, different combinations of subjects and objects of agency are possible; colored arrows in Fig. 2b denote those that have been investigated to date.

Green arrows in Fig. 2b denote the subject-object combinations investigated by Reddish et al. (2020). Participants in this study performed continuous forearm movements in synchrony with a metronome either while watching an ostensibly live-stream (but in reality, pre-recorded) video of another person moving their arm at the same or different frequency (thus in or out of synchrony with them; Experiment 1) or while a confederate moved their arm in synchrony with them (Experiment 2). As denoted by the thick green arrows in Fig. 2b, participants rated their sense of *self-agency* over their *partner's part* of the joint action (that is, their own agency over the movement of "the other arm") and their sense of *partner-agency* over the participant's *own part* of the joint action (that is, how much the "other arm" had agency over their own movements). Considering these ratings together revealed that when people moved in synchrony with each other, each person experienced some agency over their partner's movements. Specifically, self-agency over the partner's part and partner-agency over one's own part were both higher when people moved in synchrony compared to out of synchrony with a partner, and moving in synchrony elicited similar levels of self-agency over the partner's part and partner-agency over one's own part regardless of whether partners synchronized intentionally or unintentionally. Furthermore, this pattern of "mutual agency" was modulated by people's roles within the joint action: Holding the role of leader (who heard the metronome and was instructed that the partner must follow) boosted self-agency over the partner's part, whereas holding the role of follower boosted partner-agency over one's own part. As denoted by the thin green arrows in Fig. 2b, in Reddish et al.'s (2020) second experiment participants were also asked to rate their

sense of *self-agency* over their *own part* of the joint action as well as their sense of *joint agency* over the *joint outcome*. Holding the role of follower reduced self-agency over one's own part, which was otherwise high in all other conditions, indicating that mutual agency does not necessarily occur at the expense of strong self-agency. Furthermore, people reported a moderate degree of joint agency in all conditions; joint agency did not differ depending on whether or not people intentionally synchronized or held a leader versus follower role. Instead, joint agency was positively correlated with both perceived synchrony and perceived joint success.

Orange arrows in Fig. 2b denote the subject-object combinations investigated by Christensen et al. (2021), who had partners produce simple musical duets together using electronic music boxes (see Novembre et al., 2015). Each person rated their sense of *self-agency* over their *own part* (e.g., the melody), *self-agency* over their *partner's part* (e.g., the accompaniment), and *joint agency* over the duet as a whole. The perceptual distinguishability of each person's duet part was manipulated through which part they performed (melodies were more perceptually salient due to their familiarity and higher pitch range) and the distance between the melody and accompaniment (accompaniments were either nearer or farther in pitch from the melody). Perceptual distinguishability influenced participants' sense of self-agency over their own part, consistent with previously reviewed evidence that self-agency is influenced by individual-level factors such as sensorimotor and perceptual information. In contrast, perceptual distinguishability did not impact self-agency over the partner's part or joint agency. Instead, joint agency was positively correlated with the pair's synchronization performance, echoing similar findings from Reddish et al. (2020).

The findings reviewed in this subsection offer points of both convergence and divergence with findings reviewed in other subsections. Points of convergence include that self-agency was influenced by individual-level factors (here, holding a follower role and performing a more perceptually distinguishable part, converging with evidence from the "Explicit judgments of self- and partner-agency for a joint outcome" and "Explicit judgments of self-, partner-, and joint agency for a joint outcome" subsections) and that joint agency was strongly influenced by coordination between partners (converging with evidence from the "Explicit judgments of joint agency for a joint outcome" subsection). However, a key point of divergence is that joint agency was not influenced by other factors, such as people's intention to coordinate or the distribution of roles within the joint action. One feature that distinguishes the studies reviewed in this subsection is that they employed tasks that involved *synchronizing* actions with a partner, whereas studies in other subsections asked people to take turns performing actions (e.g., producing tones) and/or perform complementary actions (e.g., horizontal and vertical



movements). Thus, coordination may be an especially powerful cue to joint agency when synchrony is an explicit or implicit goal of the joint action. The studies reviewed in this subsection also highlight a need for future work to consider whether self-agency over the joint outcome is conceptually distinct from self-agency over one's own part of the joint action, and whether the "mutual agency" indexed by ratings of self-agency over the partner's part and partner-agency over one's own part is conceptually distinct from joint agency.

### Explicit judgments of togetherness and integration

As discussed in the "Overview" subsection and evident in Table 1, nearly all studies of explicit agency in joint action have asked people to rate their sense of *control* while performing a joint action. The final studies reviewed here instead probed people's sense of *joint agency* over the *joint outcome* by asking people to rate their sense of "togetherness" and "integration" with their partner. These studies provide evidence that factors other than coordination influence joint agency even in tasks that explicitly require synchronization (cf. the "Explicit judgments of agency for individual contributions to a joint act" subsection).

Both of the studies reviewed in this subsection employed tasks that required synchronization between partners, and both provide evidence that coordination is not the only factor that influences joint agency even when synchrony is an explicit task requirement. First, Noy et al. (2015) recorded participants' movements and heart rates while they played a mirror game, i.e., while they mirrored each other's improvised movements along parallel horizontal tracks under instructions to create interesting, synchronized movements together. After game play, they watched videos of the games and provided continuous ratings of their sense of togetherness. Periods of togetherness tended to co-occur with periods of heightened coordination between players' movements, but togetherness also occurred during periods of very little movement. Thus, people can have a sense of joint agency even in moments that are nearly absent of (coordinated) movement. Second, Zhou et al. (2021) had partners synchronize tone sequences together using electronic music boxes and rate the extent to which they felt integrated with their partner during each sequence. The tone sequences were designed to create joint outcomes that either entailed a simple temporal relation between parts (each person produced a series of unchanging pitches and participants' goal was to synchronize pitch onsets) or additionally included more complex metrical and harmonic relations between parts (partners produced musical duets comprised of familiar melodies and accompaniments). Synchronization performance was strongly correlated with joint agency, consistent with findings reviewed in the "Explicit judgments of agency

for individual contributions to a joint action" subsection. However, people also reported stronger joint agency when the joint outcome entailed rich compared to simple relations between individual parts, despite equivalent synchronization performance in both cases. Furthermore, Zhou et al.'s (2021) mixed-methods approach included post-experiment interviews about participants' sense of joint agency in each condition. Thematic analysis of people's responses revealed that they attributed differences in joint agency to not only their perceived degree of coordination, but also to their previous knowledge of the music and ability to predict upcoming musical events, as well as to the perceived difficulty and enjoyability of each task. These findings provide further evidence that factors other than coordination impact joint agency during synchronization tasks.

Two other findings from these studies are worth noting here. First, Noy et al. (2015) found that periods of togetherness in the mirror game were accompanied by increased heart rate, regardless of participants' movement intensity, suggesting that joint agency may induce a physiological response related to task enjoyment. This converges with participants' reports that task enjoyment influenced joint agency in Zhou et al.'s (2021) musical coordination task. Further research will be required to determine the causal direction of the link between joint agency and task enjoyment. Second, Noy et al. (2015) reported that there were substantial individual differences in the range of togetherness values people reported, even within the same pair. This finding converges with evidence of minimal correlations between partners' joint agency ratings in other studies (e.g., Loehr, 2018); together, these findings provide evidence that people engaged in the same joint action do not necessarily share the same sense of agency and indeed may have substantially different agency experiences (see also Footnote 2).

### Summary of investigations of explicit agency in joint action

In sum, the "Explicit judgments of agency" section reviewed research on explicit agency in joint action from the perspective of the different subjects and objects of agency under investigation in each study. Reviewing the literature from this perspective highlights the need to account for the multilevel nature of both the subjects and objects of agency in joint action (Fig. 1c), as well as the different combinations of subjects and objects that can therefore be investigated (Fig. 2). Likewise, considering the multilevel nature of the factors that impact agency in joint action (Fig. 1c) facilitates our understanding of their differential impacts across studies; future research should take into consideration whether factors being examined fall at the individual or collective levels or pertain to the relation



between partners. The studies reviewed in this section (and summarized in Table 1) permit several conclusions to be drawn about the factors that impact explicit agency during joint action. First, some factors have a consistent and strong impact on individual- or collective-level agency. For example, sensorimotor cues such as visuomotor coupling and action-effect distinguishability have strong impacts on self-agency, whereas perceived and measured coordination have a strong impact on joint agency. Second, some factors have less consistent impacts on agency in joint action. For example, people's roles within a joint action have had inconsistent effects across studies. This can be attributed in part to differences in how roles are defined across studies, as evident in the Factors' Operationalization column of Table 1. However, the effects of certain roles have been inconsistent even among studies that defined them in the same way. Examples include different effects of decider-follower roles on self-agency reported in van der Wel (2015) and Le Bars et al. (2020a), and different effects of leader-follower roles on joint agency reported in Bolt et al. (2016) and Shiraishi and Shimada (2021). These differences could potentially indicate a need to consider how different factors are weighted within a given joint action context (e.g., effects of role might differ depending on its salience relative to the other factors present in a given context).

Although one major focus of the research on explicit agency reviewed in this section was the type and degree of joint agency people experience during joint action, these studies primarily shed light on *shared agency* (i.e., the sense that agency is distributed among co-actors; see the "Subjects of agency in joint action" section). Few conclusions can be drawn from these studies regarding people's sense of *united agency* (the sense that co-actors are acting as a single unit) or *external agency* during joint action. Fortunately, there are a number of qualitative investigations of joint action that include first-hand accounts of people's experiences of agency during joint action, which shed particular light on united and external agency in joint action. These studies are reviewed next.

## First-hand accounts of united and external agency

This section reviews qualitative investigations of joint action that further our understanding of united and external agency. Although these studies did not specifically set out to investigate agency in joint action, they nevertheless provide evidence regarding the contexts and factors that elicit and strengthen united and external agency, which complements evidence from the investigations of self, partner, and shared agency reviewed in the "Explicit

judgments of agency" section. Notably, all of the studies reviewed in this "First-hand accounts of united and external agency" section examined real-world and/or large-scale joint actions, in which united and external agency may be more likely to occur (see, e.g., Andersen et al., 2019; Pacherie, 2012). Findings reviewed in this section thus also highlight potential avenues for further research purposefully designed to examine agency in large-scale and/or real-world joint actions. Table 2 provides an overview of the studies reviewed in this section, including which type of agency is illuminated by each study, the joint action context in which it occurred, illustrative quotes from first-hand accounts of agency in joint action, and the key insights about agency gained from each study.

### Agency during "strong experiences with music"

A unique resource for first-hand accounts of agency in joint action is Gabrielsson's (2011) book, *Strong Experiences With Music*. This book compiles people's accounts of their strongest, most intense, or most profound experiences with music. The book contains over 500 accounts, representing over 1,300 accounts originally collected in Sweden from over 900 people ranging in age from 13 to 91 years. Descriptions of *united agency* can be found throughout the book, although most are found in Chapters 18 and 19, which contain accounts of strong experiences when performing music oneself and while singing in a choir, respectively. Table 2 lists the specific accounts from which the following insights about united agency during musical joint action are drawn, and provides example quotes to illustrate each insight. As shown in the first three rows of Table 2, people's accounts of united agency document the variety of contexts in which united agency can arise. Numerous accounts describe a sense of united agency when making music as part of a large group, such as singing in a choir or performing in an orchestra, in line with Pacherie's (2012) foundational work hypothesizing that united agency should be most likely to occur in large-scale joint actions. Importantly, though, several accounts describe a sense of united agency when making music with only one or two other people, that is, when playing in a duo or trio. Numerous accounts also indicate that a sense of united agency can also occur in audience members who find themselves moving along with live music. Furthermore, people often perceive that their sense of united agency is shared by other performers and even by members of the audience, and they sometimes confirm this after the musical interaction is over (e.g., accounts 18.1D and 18.1F). These accounts highlight a need for future research to investigate the conditions under which the sense of agency is or is not shared among co-actors

**Table 2** Studies reporting first-hand accounts of united and external agency

| Authors            | Type of agency and joint action context  | Illustrative quote  | Key insights about agency in joint action  |
|--------------------|--|---|--|
| Gabrielsson (2011) | United agency in large group music-making (7.2E, 18.1D, 18.1F, 18.6B, 19.3A, 19.4B, 24.H) <sup>a</sup> | “Everybody—the orchestra, the soloists, our conductor and the choir—we were one.” (p. 260)  | <ul style="list-style-type: none"> <li>• United agency occurs in large- and small-scale musical joint action</li> <li>• Partner-agency over one’s own part and external agency also occur in musical joint action</li> <li>• People perceive that their sense of united agency is shared with co-actors</li> <li>• United agency is linked with subsequent social bonding</li> </ul> |
|                    | United agency in a small group music-making (18.1C, 18.1I, 18.3B, 18.6H, 18.6K)                        | “Suddenly everything falls into place as if <i>one</i> person was playing—not several—for a few seconds.” (p. 245)  |  |
|                    | United agency as an audience member moving along with the music (7.5A, 7.5B, 25.1C, 26.F, 27.I)        | “It became one unit, the audience and the musicians, the boundaries between different roles merged together.” (p. 340)  |  |
|                    | Co-performer’s agency over own actions in large group music-making and dancing (18.6F)                 | “It was quite simply as if it wasn’t me who was playing but the dancers who were playing me.” (p. 245)  |  |
| Stephens (2020)    | External agency in small and large group music-making (7.5C, 18.1O, 18.6B, 18.6I, 18.6K)               | “Somebody started a tune and then we all joined in. It was so simple to find the right buttons... It felt as if somebody else was controlling my hands.” (p. 245)       | <ul style="list-style-type: none"> <li>• United agency fluctuates throughout a musical joint action</li> <li>• Reductions in united agency prompt corrective behaviors that facilitate coordination</li> <li>• People sense united agency of actions and the joint outcome</li> </ul>  |
|                    | United agency in a large community choir   | “It’s almost like you become—you’re not 200 individual people, you’re one person, one entity that’s working together.” (p. 16)  |  |
| Silverman (2018)   | United agency in large group music-making and dancing  | “This is not just my energy. We’re “together.” We’re really “one.” (p. 17)  | <ul style="list-style-type: none"> <li>• Mutual responsiveness between leader and followers and visual access to other performers might facilitate united agency</li> </ul>  |
| Olaveson (2004)    | United agency among people participating in raves  | “[E]veryone one has a shared experience of connectedness and hundreds or even thousands of people can feel like one being with a shared purpose and direction.” (p. 85) | <ul style="list-style-type: none"> <li>• Breadth of contexts in which united agency occurs</li> </ul>  |
| Sato (1988)        | United agency among riders in a Japanese motorcycle gang   | “When our minds become, become one.... When all of us become one, I understand something. ... When we realize that we become one flesh, it’s supreme.” (p. 113)         | <ul style="list-style-type: none"> <li>• Breadth of contexts in which united agency occurs</li> </ul>  |
| Jackson (1992)     | United agency within pair figure skaters   | “[H]er mind and my mind were clear and in the same ... in a partnership. ... That day was really a marriage of [my partner] and [myself] and the ice.” (p. 173)         | <ul style="list-style-type: none"> <li>• Breadth of contexts in which united agency occurs</li> </ul>  |

<sup>a</sup>Numbers in parentheses indicate accounts from Gabrielsson (2011), labeled by chapter number (preceding the period), section number (following the period), and account number (final letter)

(cf. the “Explicit judgments of agency for individual contributions to a joint action” section). Finally, several descriptions explicitly link the sense of united agency during performance with later social bonding between co-performers.

The fourth and fifth rows of Table 2 illustrate that the first-hand accounts in Gabrielsson (2011) encompass not only united agency but also two other forms of agency in joint action. First, one account documents a sense that co-performers (dancers) have agency over the person’s own (music-making) actions. This provides a real-world example of *partner-agency* over one’s *own part* that complements findings reported in the “Explicit judgments of agency for individual contributions to a joint action” section (see also Fig. 2b). Second, several accounts document a sense of *external agency*, either on its own or accompanying a sense of united agency. These descriptions highlight musical joint action as a potentially fertile ground for further systematic investigation of external agency during joint action.

### Agency in other joint action contexts

The last five rows of Table 2 highlight the wider variety of joint action contexts in which first-hand accounts of united agency have been documented and the key insights provided by these accounts. First, the sense of united agency features heavily in Stephens’ (2020) ethnographic case study of how performers maintain continuous coordination with each other while singing together in a large, highly skilled community choir. Stephens’ (2020) work reveals that performers’ sense of united agency ebbs and flows over the course of a musical joint action and, more importantly, that a perceived reduction in, or absence of, united agency triggers corrective behaviors and attentional shifts that facilitate a return to coordination. Stephens’ (2020) findings also provide evidence that people have a sense of united agency with respect to the joint outcome of their actions (that is, the group’s musical output), separately from a sense of united agency with respect to the group’s actions. United agency with respect to the joint musical outcome is also evident in some of the descriptions in Gabrielsson (2011) (e.g., accounts 5.4A and 19.4D). Together, these studies highlight a need for future work to consider whether agency for *actions* is commensurate or dissociable from agency for *action-effects*. Second, the sense of united agency appears in Silverman’s (2018) investigation of students’ experiences while completing a university course in West African singing, drumming, and dancing. Reports in this study additionally suggest that united agency might be facilitated by mutual responsiveness between leader and followers and by enhanced visual access to other performers via the setup of the physical space (sitting in a circle vs. in rows). First-hand accounts of united agency also appear in people’s descriptions of dancing at

raves (Olaveson, 2004; see also Bernard, 2018) and engaging in group motorcycle rides (Sato, 1988), as well as among elite athletes such as national champion pair figure skaters (Jackson, 1992; see also Jackson, 1995, and Taylor & Cohen, 2019, for suggestive evidence that united agency might occur in larger team sports contexts). Finally, MacNeill (1995) describes examples of people “feeling they are one” (p. 8) when they engage in military drill and battle, as well as in communal dancing, in his influential account of the emotional and social impacts of activities that promote united agency over the course of human history.

### Summary of first-hand accounts of agency in joint action

In sum, the studies reviewed in this section complement those reviewed in the “Explicit judgments of agency” section by illuminating the breadth of contexts in which united agency can occur and documenting at least one context in which external agency can occur (i.e., group music performance; Gabrielsson, 2011). They provide preliminary evidence regarding the factors that might promote united agency (e.g., Silverman, 2018) and the potential consequences of experiencing united agency for other cognitive (e.g., Stephens, 2020) and social processes (e.g., Gabrielson, 2011). They highlight other important questions for future research, such as whether agency for actions should be considered separately from agency for action-effects and under what circumstances (and to what degree) the sense of agency is mutually shared by people engaged in a joint action. Finally, the research reviewed in this section highlights the potential value of mixed-methods approaches for investigating the sense of agency for larger-scale joint actions that are difficult to recreate in a laboratory environment or to capture using simple rating scales.

Having reviewed studies that examined explicit judgments of agency as well as first-hand accounts of agency in joint action, the “Implicit agency” section turns to investigations of *implicit agency* in joint action.

## Implicit agency

### Overview

This section reviews research that examined implicit agency during joint action. Because one focus of research on implicit agency during joint action concerns which *subjects* of agency are captured by each measure of implicit agency (i.e., individual- versus collective-level subjects; see Fig. 1a), this section is organized according to, first, the implicit measure used in each study, and second, the

*objects* of agency under investigation in each study. Organizing the literature in this way illuminates evidence that temporal binding, the most commonly investigated measure of implicit agency in joint action, might reflect the collective-level subject *we*, at least in some joint action contexts, whereas sensory attenuation, a second measure of implicit agency that has received less attention in the joint action literature, might instead reflect differentiation between individual-level subjects (self vs. partner). The “Temporal binding” and “Sensory attenuation” subsections review studies of temporal binding and sensory attenuation in joint action, respectively. The “Other measures of implicit agency” subsection describes a study that used skin conductance as an implicit measure of agency in joint action. The left half of Table 3 provides an overview of each study reviewed in this section, including the joint action tasks employed; the implicit measures<sup>7</sup> and objects of agency<sup>8</sup> investigated; the facets of explicit agency participants rated (as applicable in studies that measured implicit and explicit agency concurrently); and key findings. Although this section focuses less on the factors that influence implicit agency compared to the “Explicit judgments of agency” section, the right half of Table 3 lists the factors that were examined in each study, describes how they were operationalized, and summarizes their key effects.

## Temporal binding

Temporal binding (also referred to as intentional binding; Moore & Obhi, 2012) is the phenomenon whereby the perceived time interval between actions and their perceptual consequences is subjectively compressed, because actions are perceived as later in time than they actually occurred, and action-effects are perceived as earlier in time than they actually occurred (Haggard et al., 2002). Some studies measure temporal binding using a version of the Libet clock procedure (Libet et al., 1983), in which participants watch the rotating hand of a clock and report the clock time at which they perceive an action or action-effect to have occurred. Temporal binding is then estimated by

comparing the perceived event time to the true time of its occurrence (separately for actions and/or effects) or by calculating the perceived interval between actions and effects relative to the true interval. Other studies measure temporal binding by asking people to directly estimate the length of the interval between an action and its effect. The mechanisms underlying temporal binding are still under debate, particularly with respect to whether binding results specifically from action intentions and/or from more general perceptions of causality (see, e.g., Hoerl et al., 2020; Kirsch et al., 2019; Schwarz et al., 2019). Regardless, investigations of temporal binding in joint action contexts shed light on implicit agency for both the individual parts of a joint action as well as its joint outcome, as reviewed next.

### Temporal binding for individual contributions to a joint action

As shown in Table 3, the studies reviewed in this subsection examined temporal binding for the *individual parts* of a joint action. These studies provide evidence that people show temporal binding for actions and effects produced by themselves *and* for actions and effects produced by their partner, even though their explicit judgments of agency attribute responsibility to either themselves *or* their partner. Thus, these studies show that people have a sense of implicit agency for both their own *and* their partner’s parts of a joint action and that implicit agency is dissociable from explicit judgments of individual-level agency.

A series of early studies by Obhi and colleagues demonstrated that people show binding for both their own and their partners’ parts of a joint action. Obhi and Hall (2011a) asked pairs of participants to place one finger each on a single shared response key. One person (the “initiator”) pressed the key at a time of their choosing and the other person (the “responder”) reacted to the initiator’s key-press by also pressing the key. A tone sounded 200 ms after the initiator’s key-press.<sup>9</sup> Participants judged the onset time of either the *initial* key-press or the tone. They also provided explicit judgments about whether they or their partner was responsible for the initial key-press or the tone. People showed binding between key-presses and tones they attributed to themselves *and* between key-presses and tones they attributed to their partner (compared to baseline conditions in which they judged key-presses in the absence of tones or vice versa). Furthermore, binding occurred for both own

<sup>7</sup> The ‘Implicit Measure’ column of Table 3 includes details about how implicit agency was measured that differ across studies that use the same technique (e.g., for temporal binding, whether participants judged actions, effects, or the interval between actions and effects; for sensory attenuation, whether it was measured from perceptual ratings or auditory ERPs). Although these details are not critical for understanding the overall patterns of findings across studies, they may be relevant for researchers planning future investigations of implicit agency.

<sup>8</sup> For studies that examined implicit agency for the individual parts of the joint action, the Object column of Table 3 specifies whether actions and/or action-effects were examined (e.g., studies of temporal binding typically investigated both actions and action-effects, whereas studies of sensory attenuation examined action-effects only).

<sup>9</sup> Temporal binding studies always entail a delay between actions and their effects. Some studies assess binding at a single delay and others at several different delays. Because differences between delays are not of critical interest here, the text that follows often references the delay(s) using phrasing such as “key-press elicited a subsequent tone.”

**Table 3** Studies examining implicit agency

| Subsection  | Authors<br>•Task   | Implicit measure          | Object                             | Facet rated  | Key findings  | Factors examined        | Factors' operation-<br>alization   | Factors' key effects  |
|---|--|---------------------------|------------------------------------|--------------|---|-------------------------|--|---|
| Temporal binding for individual contributions to a joint action | Obhi and Hall (2011a)<br>•Press shared key to elicit tone  | Binding<br>•Judge A and E | Own and partner's A/E <sup>a</sup> | Causal resp. | Binding for both self <i>and</i> partner despite explicit agency for self <i>or</i> partner                       | Role                    | Initiator presses first, responder actively joins in   | Similar binding for both roles                              |
|   | Strother et al. (2010)<br>•Press shared key to elicit tone | Binding<br>•Judge A and E | Own and partner's A/E              | Causal resp. | Binding for both self <i>and</i> partner despite explicit agency for self <i>or</i> partner                       | Role                    | Assigned in advance or emerges in task<br>Initiator presses key first, responder moves passively | No difference in binding<br>Similar binding for both roles  |
|   | Obhi and Hall (2011b)<br>•Press shared key to elicit tone  | Binding<br>•Judge A and E | Own and partner's A/E              | Causal resp. | With a human partner: Binding for both self <i>and</i> partner despite explicit agency for self <i>or</i> partner | Belief re: partner type | Assigned in advance or emerges in task<br>Participants believe partner is human or computer      | No difference in binding<br>Binding only with human partner |
| Feedback re: causal resp.                                       |  |                           |                                    |              |   |                         |  | False feedback indicates self or partner caused tone        |
|   |  |                           |                                    |              |   |                         |  | Beliefs modulate explicit agency but not binding            |



**Table 3** (continued)

| Subsection                                   | Authors<br>•Task   | Implicit measure            | Object                   | Facet rated              | Key findings  | Factors examined                     | Factors' operation-<br>alization   | Factors' key effects  |
|--|--|-----------------------------|--------------------------|--------------------------|---|--------------------------------------|--|---|
| Temporal binding<br>for a joint out-<br>come | Grynszpan et al.<br>(2019)<br>•Rotate handles<br>together                        | Binding<br>•Judge intervals | Joint outcome            | Causal contri-<br>bution | With a human<br>partner: Binding<br>between actions<br>and a joint out-<br>come   | Role                                 | Initiator moves<br>handle first, fol-<br>lower joins in                                      | Similar binding for<br>both roles                           |
|  | Jenkins et al.<br>(2021)<br>•Move mouse to<br>target and click to<br>elicit tone | Binding<br>•Judge intervals | Joint outcome            | None                     | Similar binding<br>for joint and solo<br>action                                   | Partner type                         | Participants inter-<br>act with human<br>or robot  | Binding only with<br>human partner                          |
|  | •Coordinate key-<br>presses to elicit<br>tone                                    |                             |                          |                          | Reduced binding<br>for cued joint<br>action                                       | Role                                 | One partner moves<br>to target, one<br>clicks to elicit<br>tone                              | No difference in<br>binding                                 |
|  | Hayashida et al.<br>(2021)<br>•Coordinate key-<br>presses to elicit<br>tone      | Binding<br>•Judge intervals | Joint outcome            | None                     | Similar binding<br>for joint and solo<br>action; modulated<br>by consequences     | Consequence for a<br>third party     | Leader provides a<br>verbal countdown<br>cue   | No difference in<br>binding                                 |
| Temporal binding<br>for prompted<br>actions  | Pfister et al. (2014)<br>•Leader prompts<br>follower to act                      | Binding<br>•Judge intervals | Own and partner's<br>A→E | None                     | Leaders do not<br>show binding<br>between fol-<br>lower's action &<br>effect      | Role                                 | Leader's key-press<br>elicits a tone,<br>which prompts<br>follower to act                    | Only leaders show<br>binding                                |
|  | Capozzi et al.<br>(2016)<br>•Leader prompts<br>follower to act                   | Binding<br>•Judge E         | Own and partner's<br>E   | None                     | Leader perceives<br>own tones as<br>early but fol-<br>lower's tone as<br>delayed  | Cooperative/com-<br>petitive context | Coordinate as if to<br>create a melody<br>vs. follower<br>should 'wipe out'<br>leader's tone | No difference in<br>binding                                 |
|  | Caspar et al. (2018)<br>•Commander<br>instructs agent<br>to act                  | Binding<br>•Judge intervals | Own and partner's<br>A→E | Overall resp.            | Commanding<br>induces explicit<br>agency but not<br>binding for<br>other's action | Role                                 | Commander<br>instructs agent<br>to act   | Commanding<br>induces explicit<br>agency but not<br>binding |

Table 3 (continued)

| Subsection                           | Authors<br>•Task  | Implicit measure                | Object                 | Facet rated | Key findings   | Factors examined         | Factors' operation-<br>alization   | Factors' key effects  |
|--------------------------------------|---|---------------------------------|------------------------|-------------|--|--------------------------|--|---|
| Sensory attenuation                  | Loehr (2013)<br>•Coordinate key-<br>presses to elicit<br>tone   | Atten.<br>•Aud. N1 ERP          | Joint outcome          | None        | N1 atten. dif-<br>ferentiates own<br>from partner's<br>contributions   | Action-effect<br>timing  | Partners press<br>nearly simultane-<br>ously; tone elic-<br>ited after second<br>press | Atten. only when<br>own action elicits<br>tone                  |
|                                      | Weiss et al. (2011)<br>•Press key to elicit<br>tone             | Atten.<br>•Perceived volume     | Own and partner's<br>E | None        | Atten. stronger for<br>own than partner<br>tones                       | Role                     | Participant prompts<br>vs. is prompted<br>E  | Prompting induces<br>atten. for partner's<br>E                  |
|                                      | Bolt and Loehr<br>(2021a)<br>•Produce tone<br>sequences         | Atten.<br>•Aud. N1 & P2<br>ERPs | Own and partner's<br>E | None        | P2 atten. differenti-<br>ates own from<br>partner's contri-<br>butions | Agent                    | Tone produced by<br>self or partner  | Agent affects audi-<br>tory P2 atten. but<br>not N1 atten.      |
| Other measures of<br>implicit agency | Le Bars, Devaux,<br>et al. (2020b)<br>•Move cursor to<br>target | Skin conduct.                   | Joint outcome          | See Table 1 | Skin conduct-<br>ance affected by<br>reward distribu-<br>tion          | Reward distribu-<br>tion | Equal vs. fair vs.<br>randomly all-or-<br>none   | Reduced skin con-<br>ductance for fairly<br>distributed rewards |

A Action, E Effect, Atten Attenuation, Aud Auditory, Conduct Conductance, Resp Responsibility

<sup>a</sup> A/E is used when participants judged individual events and A→E is used when participants judged intervals

and partners' actions regardless of whether the roles of initiator and responder were assigned in advance or emerged spontaneously on each trial. This same pattern of findings – binding for both own and partners' actions, whether roles were assigned in advance or emerged spontaneously – was also evident in a study by Strother et al. (2010), which used the same paradigm but had responders simply allow their finger to passively move along with the initiator's key-press. Obhi and Hall (2011a) interpreted these findings as initial evidence that people might form a “joint agentic identity” wherein they “operat[e] as a unified agent” at the pre-reflective level (p. 656), and thus show binding for actions and effects produced by either agent involved in the joint action. According to this interpretation, temporal binding could be considered to reflect the collective-level subject (we) rather than individual-level subjects (self or partner).

A third study using the same paradigm additionally revealed that people show binding for their partner's actions when interacting with a human but not a computer partner. Obhi and Hall (2011b) had participants perform the key-press task with a human partner (a confederate who was hidden from view by a curtain) and with a computer partner (that was ostensibly simulating a human partner's actions). In reality, the participants always heard a tone 200 ms after their own key-press, but received false feedback indicating that either they or their partner had pressed the key first. When participants interacted with a human partner, they showed binding both for tones they believed were produced by themselves and for tones they believed were produced by their partner. In contrast, when participants interacted with a computer partner, they did not show binding for tones they believed were produced by the computer. This finding suggests that binding for a partner's actions may be limited to human-human interactions in which people form mental representations of both their own and their partner's actions. This conclusion is further supported by evidence that people form mental representations and show temporal binding for a human's actions, but not computer-simulated actions, when they engage in parallel stimulus-response compatibility tasks (Sahaï et al., 2019; see also Sahaï et al., 2017, for a review of investigations of implicit agency during human-computer interaction).

In sum, the studies reviewed in this subsection establish that people show temporal binding for both their own and a human partner's actions during joint action. However, in these studies partners shared the goal of responding to each other's key-presses but not necessarily the goal of producing a “joint” outcome; indeed, they attributed the outcome to one partner or the other and, in reality, the initiator's action-effect could occur regardless of whether or not the responder performed their action. The next subsection reviews studies that investigated temporal binding for action-effects that were perceived to be and/or were authentically joint

outcomes, that is, that were jointly produced by both partners' coordinated actions.

### Temporal binding for a joint outcome

The studies to be reviewed next examined temporal binding for the *joint outcome* of two partners' coordinated actions. These studies provide evidence that both partners show binding between their actions and the joint outcome, and that people show a similar degree of binding whether they produce actions together with a partner or alone.

Grynszpan et al. (2019) had partners perform a joint handle rotation task in which they each rotated separate handles until they reached a stopping point that elicited a subsequent tone. The handles were either linked together (so that forces applied by each partner were felt by the other partner) or controlled by a robot (which applied forces to simulate a human partner's movements). Participants believed they were performing the task with their human partner throughout the experiment, but in reality, the human partner was replaced by the robot in one of two experimental blocks. Compared to a baseline condition, people showed temporal binding between their actions and the joint outcome when they interacted with the human partner but not when they interacted with the robot. Thus, reduced binding when interacting with a non-human partner can arise solely from kinesthetic (bottom-up) information about the partner's movements, complementing previous reports of reduced binding based on (top-down) beliefs about the partner's biological status (Obhi & Hall, 2011b). Moreover, when interacting with a human partner, people showed equivalent binding whether they held the role of initiator, who began moving the handle first, or follower, who joined in after the initiator began moving. Importantly, both partners reported a sense of explicit *joint* agency in this task: initiators rated their contribution to causing the tone as ~60/100 and followers as ~40/100. Thus, temporal binding is similar across partners whether agency is attributed to one partner or the other (as discussed in the “Temporal binding for individual contributions to a joint action” subsection) or is shared between partners, further supporting the notion that temporal binding might reflect the collective-level subject *we*.

Binding is likewise similar across partners even when action parameters differ between them. Jenkins et al. (2021) had participants use a mouse to move a cursor to a near or far target and then click the mouse button to elicit a subsequent tone. Participants performed the task alone or together with a partner, in which case both partners placed their hand on the mouse, one partner moved the mouse, and the other clicked the mouse button. Binding did not differ between the roles of mover and clicker, even though only the clicker was responsible for the action that elicited the tone.

Furthermore, binding was equally modulated by distance for both the mover and the clicker, even though only the mover's action changed with distance. Thus, binding did not differ between the individual parts of the joint action (click the mouse or move a certain distance). Furthermore, binding did not differ between performing the task with a partner versus performing the task alone. That is, binding was similar whether a person performed *part* of the task to achieve a goal with a partner or performed the *complete* task to achieve the same goal alone. Together, these findings provide evidence that temporal binding reflects the (collective) subject that achieves the (collective) goal of the joint action.

Jenkins et al. (2021) also reported a second experiment that compared temporal binding for actions produced alone versus together with a partner. In this experiment, participants made key-presses that elicited subsequent tones either alone or in coordination with a partner. People showed reduced binding in the joint condition compared to the solo condition; however, this may have occurred because participants provided a verbal countdown to coordinate their key-presses only in the joint condition (Jenkins et al., 2021). Indeed, Hayashida et al. (2021) found no difference between binding for actions performed jointly versus alone using a similar paradigm that, critically, included a visual countdown before both joint and solo key-presses. Together, then, these studies suggest that similar binding occurs for actions performed alone versus together with a partner, although further work is needed to definitively establish whether and when binding is equivalent between joint and solo action. Finally, Hayashida et al. (2021) also reported that temporal binding for a joint outcome was modulated by the consequences of the outcome for a third person who was not directly involved in the task. Specifically, people showed reduced binding for a jointly-produced outcome compared to a self-produced outcome when the outcome signaled a large loss (rather than a small or no loss) for the third party. Thus, performing a harmful action together with a partner reduces implicit agency compared to performing the same harmful action alone.

Together, the studies reviewed in this subsection provide evidence that temporal binding reflects the collective-level subject when people coordinate their actions to produce a joint outcome. The studies to be reviewed next, however, indicate a boundary condition for this relationship between temporal binding and the collective-level subject of a joint action.

### Temporal binding for prompted actions

The studies reviewed thus far demonstrate that people engaged in joint action show temporal binding for their own and their partner's actions as well as for a joint outcome. The studies to be reviewed next identify a boundary condition

for temporal binding of others' actions: it does not occur in sequential joint actions in which one partner prompts the other to produce a subsequent action.

Pfister et al. (2014) employed a sequential joint action task in which the leader pressed a key that elicited a subsequent tone, which prompted the follower to press a key (which, in one of two experiments, also elicited a subsequent tone). Compared to followers, leaders showed binding for the interval between their own action and its effect and between their own effect and the follower's subsequent action, but did not show binding for the interval between the follower's action and its effect. That is, prompting someone to act did not elicit temporal binding for that person's action-effect interval. Although this study provided initial evidence that temporal binding might not extend to the next person's action within a sequential joint action, an alternative possibility is that participants simply did not hold a salient joint goal because task instructions focused on judging intervals (Pfister et al., 2014). However, Capozzi et al. (2016) confirmed that temporal binding does not extend to the next person's action even when participants do hold a salient joint goal. In their study, participants always produced the first key-press, which elicited a subsequent tone that ostensibly prompted their partner (a confederate) to produce a key-press and subsequent tone. Participants were instructed to perform the task cooperatively, i.e., to coordinate their actions as if to create a melody, or competitively, i.e., that the follower should act as quickly as possible to try to "wipe out" the leader's tone. Here, temporal binding was measured by subtracting the judged onset time of each tone from its true onset time. The follower's tones were perceived as occurring relatively *late*, both compared to the participant's own tones and compared to when the follower was observed producing tones alone. Moreover, delayed perception of the follower's tones occurred in both cooperative and competitive contexts, indicating that temporal binding for a follower's action-effect did not occur even when the task was explicitly cooperative. Finally, Caspar et al. (2018) demonstrated that a leader does not show temporal binding for a follower's action even when the leader directly commands the follower to act. Their study was designed to investigate agency in situations where one person commands a second person to produce an action that harms a third person. Participants alternated holding the role of a *commander*, who could deliver commands to an *agent*, who either did or did not deliver a shock to a *victim*. Regardless of whether a shock was delivered, the agent's action always elicited a subsequent tone, and both the commander and the agent judged the duration of the *agent's* action-effect interval. Commanding the agent to act *reduced* temporal binding compared to acting on one's own (echoing similar findings from Hayashida et al., 2021, reviewed in the "Temporal binding for a joint outcome" subsection), even though people's explicit ratings of responsibility were

equally high in both cases. Together, then, findings reviewed in this subsection indicate that neither prompting nor commanding someone to act elicits temporal binding between that person's action and its effect.

In sum, the studies reviewed in this subsection suggest that temporal binding does not reflect the collective-level subject in joint actions in which one person prompts another to act, because in such joint actions, people show binding for their own but not their partner's action. These studies thus highlight a need for future research to investigate whether and in what contexts temporal binding reflects the collective subject versus differentiates between individual-level subjects of a joint action.

### Sensory attenuation

A second common measure of implicit agency is sensory attenuation, whereby the sensory consequences of one's own actions are perceived as less intense, and elicit reduced neural responses, compared to externally generated sensory effects (see Horváth, 2015, and Hughes et al., 2013, for reviews of attenuation in solo action). Some studies measure sensory attenuation by asking people to report the perceived intensity of an action's sensory consequences (e.g., the perceived volume of a tone). Other studies use EEG to measure the amplitude of event-related potentials (ERPs) elicited by actions' sensory consequences. Research on sensory attenuation in joint action has to date exclusively examined attenuation in the auditory domain. One study examined attenuation using perceptual ratings of tone volume (Weiss et al., 2011). Two studies examined attenuation using auditory ERPs; specifically, the auditory N1, a negative-going potential that peaks approximately 100 ms after tone onset, and the auditory P2, a positive-going potential that peaks approximately 200 ms after tone onset (Bolt & Loehr, 2021a; Loehr, 2013). These few studies appear to demonstrate that sensory attenuation *differentiates* one's own from a partner's contributions to a joint action, that is, differentiates between individual-level subjects of agency.

One study of sensory attenuation in joint action investigated attenuation of the *joint outcome* of two people's coordinated actions, similar to studies of temporal binding for a joint outcome reviewed in the "Temporal binding for a joint outcome" section. Loehr (2013) compared sensory attenuation for tones produced alone versus tones produced in coordination with a partner. In the solo task, participants' key-presses immediately elicited a tone. In the joint task, participants' and partners' key-presses were nearly simultaneous, and a tone was elicited immediately after the second of the two key-presses. The auditory N1 ERP showed stronger attenuation for self- compared to jointly produced tones. Moreover, in the joint task, the N1 was only

attenuated on trials in which the participant's own key-press elicited the tone and was not attenuated on trials in which the partner's key-press elicited the tone. Thus, N1 attenuation differentiated between partners' contributions to the joint outcome, based on subtle differences in the temporal relationship between each person's action and the joint outcome. Sensory attenuation likewise differentiated between partners' actions in a joint action that required *one person to prompt another* to act (cf. the "Temporal binding for prompted actions" section) in a study by Weiss et al. (2011). This study examined sensory attenuation in two solo conditions, in which participants either produced tones alone or observed an experimenter producing tones alone, and in two joint conditions, in which the participant either prompted the experimenter to produce a tone (by touching their arm) or was prompted by the experimenter to produce a tone. In the solo conditions, people showed stronger attenuation for tones they produced themselves compared to tones produced by an observed experimenter. In the joint conditions, people also showed stronger attenuation for tones they produced themselves compared to tones produced by the experimenter. Thus, sensory attenuation marked a distinction between one's own and a partner's actions even within a joint action context. Finally, a study by Bolt and Loehr (2021a) showed that sensory attenuation differentiates between one's own and a partner's *individual contributions* to a joint outcome (cf. the "Temporal binding for individual contributions to a joint action" section). In their study, participants produced tones in alternation with a partner to produce sequences that matched a metronome pace. Auditory N1 and P2 ERPs were measured in response to the first sequence tone, which was produced by either the participant or the partner. Here, the auditory P2 was attenuated for self- compared to partner-produced tones; however, there was no evidence of N1 attenuation for either self- or partner-produced tones. These findings align with recent evidence that P2 attenuation might be a marker of agency (see, e.g., Timm et al., 2016), whereas N1 attenuation might instead be driven by temporal cues (that did not differ between self- and partner-produced tones because each person's action immediately elicited a tone that was clearly separated in time from their partner's tones).

In sum, few studies have investigated sensory attenuation in joint action, and those few have used different measures of attenuation. However, all three studies showed that attenuation differentiates self- from partner-produced action-effects, regardless of the joint action context. Thus, these studies could be considered preliminary evidence that sensory attenuation reflects the individual- rather than collective-level subject of agency in joint action. That said, there is a clear need for further investigation of sensory attenuation in joint action, in concert with previously described needs for further work investigating the mechanisms that underlie sensory attenuation itself (see,



e.g., Dogge et al., 2019; Hughes et al., 2013) as well as the relationship between sensory attenuation and explicit judgments of agency (e.g., Pyasik et al., 2018; Timm et al., 2016).

### Other measures of implicit agency

Finally, Le Bars et al. (2020b) examined participants' skin conductance responses as an implicit measure of agency, concurrently with their investigation of explicit agency which was already described in the "Explicit judgments of self-, partner-, and joint agency for a joint outcome" section. Recall that in this study, participants jointly moved a cursor to a target and were given rewards after each trial that were either equally shared between partners, distributed "fairly" in accordance with partners' individual contributions to moving the cursor, or randomly distributed such that one participant received the full reward and the other received no reward. Tonic skin conductance, which is thought to reflect general physiological states such as stress or emotion, was lower for blocks in which rewards were fairly distributed compared to blocks in which rewards were equally or randomly distributed. Because fair reward distribution was based on the number of key-presses made by each partner, and because research in other domains has shown that tonic skin conductance is reduced when people perceive themselves to be in control, Le Bars et al. (2020b) suggest that tonic skin conductance might reflect implicit feelings of control over the ultimate outcome of the joint action. Thus, skin conductance may be a potential third measure of implicit agency that could yield further insight into implicit agency in joint action contexts.

### Summary of implicit agency in joint action

In sum, the studies reviewed in this section provide evidence that different measures of implicit agency reflect different subjects of agency in joint action. Specifically, the studies reviewed in this section provide evidence that temporal binding reflects the collective-level subject of agency in joint action: People show temporal binding for both their own and their partner's part of a joint action; they show similar levels of binding regardless of which part of the joint action they perform; and they show similar levels of binding when they perform part of a joint action with a partner and when they perform the complete action alone. However, the studies reviewed in this section also suggest that temporal binding does not reflect the collective subject in at least one type of joint action, when one partner prompts the other to act. Further research is needed to elucidate why temporal binding reflects the collective subject in some joint action contexts but not in others. The studies reviewed in this section

also provide preliminary evidence that sensory attenuation reflects the differentiation between individual-level subjects of agency in joint action (self vs. partner) rather than the collective-level subject, and provide initial evidence that other measures such as skin conductance might also prove useful for assessing implicit agency.

Having reviewed explicit judgments, first-hand accounts, and implicit measures of agency in joint action, the final section of the review summarizes key conclusions that can be drawn from research to date and highlights several outstanding issues and questions for future investigations of agency in joint action.

### Conclusions and future directions

The present review provides an overview of research that has examined the sense of agency in joint action. One key contribution of the review is that it highlights how the multilevel nature of joint action (i.e., that it is comprised of individual-level contributions to a collective-level goal) has important implications for understanding the sense of agency in joint action. In particular, the review highlights three key implications: First, there are multiple possible subjects and objects of agency for joint action, and these also entail both individual and collective levels (see Fig. 1). The specific combination(s) of subjects and objects of agency under investigation are of critical importance for designing and interpreting studies of agency in joint action. Second, the factors that influence agency in joint action also entail both individual and collective levels, and considering them from this perspective facilitates our understanding of different patterns of effects across studies. Third, considering investigations of implicit agency from the perspective of individual- versus collective-level subjects of agency elucidates both the meaning of different measures of implicit agency and the insights that can be gained from each. More broadly, considering the implications of the multilevel nature of joint action for the sense of agency complements research that has elucidated its implications for the mental representations that underlie joint action (Sebanz & Knoblich, 2021; Vesper et al., 2010) and for computational models of coordination during joint action (Keller et al., 2016; Pesquita et al., 2017).

A second key contribution of the review is that it consolidates existing evidence about the sense of agency in joint action and illuminates questions that remain to be addressed in future research. Researchers have now amassed considerable evidence regarding how a variety of factors influence both explicit and implicit agency in joint action (Tables 1 and 3, respectively). Further research will be needed to determine why some factors have inconsistent effects across different joint action contexts and, perhaps relatedly, how

different factors are weighted when present in the same joint action context (cf. cue-integration models of agency in solo action; e.g., Moore & Fletcher, 2012). Addressing these questions using both explicit and implicit measures of agency will be critical for modeling the sensorimotor and cognitive processes underlying agency in joint action as well as how these processes are integrated. The review also highlights a need for further research investigating the neural processes that underlie agency in joint action. Notably, this research will also need to consider both individual- and collective-level neural processes (e.g., measures of individual brain activity such as the sensory ERPs discussed in the “Sensory attenuation” section and measures of inter-individual brain activity such as the inter-brain coordination discussed in the “Explicit judgments of self- and partner-agency for a joint outcome” and “Explicit judgments of joint agency for a joint outcome” sections).

Considerable progress has also been made toward understanding the sense of shared agency in joint action. As reviewed in the “Explicit judgments of agency” section, research has now established that factors such as perceived coordination and joint task success consistently promote shared agency, that shared agency is correlated with but dissociable from self-agency, and that shared agency does not simply reflect a sum or average of self- and partner-agency. In contrast, much less is known about the sense of united or external agency in joint action. The research reviewed in the “First-hand accounts of united and external agency” section highlights the potential value of first-hand accounts of agency in joint action, gathered for the express purpose of answering specific research questions, as a source of information about united and external agency in real-world, large-scale joint actions that are difficult to recreate in laboratory settings. The research reviewed in the “First-hand accounts of united and external agency” section also illuminates several intriguing questions for future research, such as whether the sense of joint agency for *actions* is commensurate or dissociable from the sense of joint agency for *action-effects* (and, relatedly, whether such a distinction would apply only to joint actions in which people’s actions have separate action-effects, as in joint music performance, or also to joint actions in which people’s actions create a single, shared action-effect, such as when nearly-simultaneous key-presses elicit a single tone). The “Explicit judgments of agency” and “First-hand accounts of united and external agency” sections also highlight a need to investigate whether and when the sense of joint agency is shared between co-actors, and how that relates to people’s *perception* of whether or not it is shared. On the one hand, studies reviewed in the “Explicit judgments of agency” section indicate that partners do not necessarily have a similar sense of *shared* agency, but on the other hand, first-hand accounts reviewed in the “First-hand accounts of united and external agency” section indicate

that people sometimes strongly perceive that their sense of *united* agency is shared with their co-actors (and even extends to audience members). Last, the “Explicit judgments of agency” and “First-hand accounts of united and external agency” sections illuminate the potential value of musical joint action and virtual reality settings as venues for further investigation of external agency in joint action, about which little is currently known.

The review also highlights progress toward understanding self-agency for both one’s own part and the joint outcome of a joint action; in particular, the research reviewed in the “Explicit judgments of agency” section has established that sensorimotor information has a strong and consistent impact on self-agency in joint action. In contrast, less is known about self-agency for a partner’s part of the joint action, or about partner-agency in general (see Fig. 2b). Here, the review highlights a need to establish and consistently use terminology that more clearly indicates the subject and object of agency under investigation. For example, self-agency over a partner’s actions is sometimes referred to as “vicarious agency” (originating from the solo action literature; e.g., Wegner et al., 2004) but has also been referred to as “extended self-agency” (Reddish et al., 2020); the latter is likely preferable because it explicitly indicates the subject of agency and implies the object of agency. Similarly, the terms joint agency, we-agency, and shared agency have sometimes been used interchangeably in the literature; care must be taken to clearly indicate whether the topic of investigation is joint agency in a broad sense or a specific type of joint agency. As noted in Footnote 1, the term united agency may be preferable over the term we-agency to avoid confusion between the subject versus type of joint agency being specified. The review also highlights other methodology-related future directions, such as determining whether the different facets of explicit agency that have been examined to date (e.g., control, causal responsibility, togetherness; see Tables 1 and 3) are conceptually distinct or tap into the same underlying construct. Similarly, further work is needed to determine whether different methods of measuring sensory attenuation (e.g., perceived volume versus the auditory N1 versus the auditory P2 ERPs) have the same or different functional relationships with implicit agency. Such work will complement ongoing efforts to address similar questions, including links between temporal binding, sensory attenuation, and explicit agency, in the solo action literature, and will further develop our understanding of which aspects of agency different measures of implicit agency tap into during joint action.

Finally, the review highlights that although researchers are beginning to understand the *antecedents* of joint agency (i.e., the factors that promote or hinder it), little research has yet examined the *consequences* of joint agency for

other cognitive and social processes. Potential directions for future work include investigating the consequences of joint agency for cognitive processes related to coordination, such as under what conditions having (or lacking) a sense of joint agency influences adaptive behavior in response to errors or failures of coordination (cf. Stephens, 2020). In a similar vein, further work is needed to investigate the causal relationship between joint agency and task performance; specifically, whether there is a bidirectional relationship between having a strong sense of joint agency and successful task performance. Future research could also investigate the causal relationship between joint agency and task enjoyment to determine, for example, whether having a strong sense of joint agency promotes engagement in cooperative behaviors with others, both in the moment of an ongoing joint action and when future opportunities arise. More broadly, future research could also investigate links between joint agency and social bonding. The first-hand accounts of joint agency reviewed in the “First-hand accounts of united and external agency” section suggest a particularly strong impact of *united* agency on subsequent social bonding. Indeed, united agency might be one element that contributes to the powerful effects of activities such as collective rituals and group music-making on social bonding (e.g., Tarr et al., 2014; Whitehouse & Lanman, 2014). Investigating the consequences of joint agency for both cognitive and social processes could potentially illuminate the value of developing and using techniques that promote joint agency in applied settings, such as in music therapy (where a sense of togetherness may be a key element of successful therapeutic practice; Overy & Molnar-Szakacs, 2009) and in psychotherapy more broadly (where evidence has already begun to accumulate that physiological and behavioral synchrony between therapists and clients predict therapeutic outcomes; e.g., Koole & Tschacher, 2016). In sum, then, the current review highlights that there is much to be gained by further research aimed at understanding the cognitive and neural processes that underlie agency in joint action, as well as the cognitive and social consequences of experiencing agency alongside one’s co-actors when performing actions together with other people.

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