Association for Psychological Science

Current Directions in Psychological Science
2021, Vol. 30(2) 138–143

DOI: 10.1177/0963721420984425
www.psychologicalscience.org/CDPS
SAGE

Progress in Joint-Action Research

Natalie Sebanz and Günther Knoblich
Department of Cognitive Science, Central European University

Abstract

Humans have a striking ability to coordinate their actions with each other to achieve joint goals. The tight interpersonal coordination that characterizes joint actions is achieved through processes that help with preparing for joint action as well as processes that are active while joint actions are being performed. To prepare for joint action, partners form representations of each other's actions and tasks and the relation between them. This enables them to predict each other's upcoming actions, which, in turn, facilitates coordination. While performing joint actions, partners' coordination is maintained by (a) monitoring whether individual and joint outcomes correspond to what was planned, (b) predicting partners' action parameters on the basis of familiarity with their individual actions, (c) communicating task-relevant information unknown to partners in an action-based fashion, and (d) relying on coupling of predictions through dense perceptual-information flow between coactors. The next challenge for the field of joint action is to generate an integrated perspective that links coordination mechanisms to normative, evolutionary, and communicative frameworks.

Keywords

joint action, coordination, communication, social interaction, social cognition

Joint actions are a fundamental part of human life. Making love, hunting together, or having a conversation requires that interaction partners adjust their actions to each other in fine-grained ways to accomplish shared goals. Some joint actions rely on a lot of expertise and training (D'Ausilio et al., 2015)—think of an orchestra performing a symphony, a team of construction workers building a bridge, or a surgical team doing a heart transplant. Others are so mundane that we hardly notice performing them. But even though everyday joint actions, such as passing a cup of tea to a friend or kicking a ball back and forth, appear simple, they involve a range of dedicated processes that support coordination.

Historically, research has focused on three aspects of joint action. First, prior work has addressed preconditions for engaging in joint action. Comparative-cognition research has demonstrated a unique motivation in human adults and children to collaborate and to engage in joint action (Tomasello et al., 2005). Philosophy of action has highlighted the importance of shared intentions, raising fundamental questions about their nature (Bratman, 2014) and leading to debates on whether shared intentions or commitments are necessary for joint action (Michael & Pacherie, 2015). Second, work on language use has established the importance of discourse as a coordination device (Clark, 1996). Conversation not only is a form of joint action in and of itself but also provides means to enhance common ground and coordinate plans and actions (Brennan et al., 2018; Jouravlev et al., 2019). Finally, research on humans' tendency to fall into synchrony during the performance of rhythmic, repetitive actions such as walking or clapping has contributed to the understanding of basic coordination mechanisms underlying interpersonal synchronization (Schmidt & Richardson, 2008).

Here, we review recent studies that have advanced the field of joint action by targeting processes that operate during immediate preparation for joint action and during performance of a wide range of joint actions. These studies have shed light on how coordination is achieved without using verbal communication and have revealed how processes of perception, action planning, and motor control are employed in the service of joint action. Specifying the processes enabling coordination not only is important for advancing our understanding of this fundamental human ability but also provides

Corresponding Author:
Natalie Sebanz, Department of Cognitive Science, Central European University
E-mail: sebanzn@ceu.edu

insights into the social nature of human minds, and it can also inform the design of robots interacting with human partners (Thomaz et al., 2016).

We will first consider the mental representations that coactors form of the tasks and actions to be performed. As we will show, representing other people's actions in similar ways as one's own actions and representing relations between actions supports coordination. Next, we provide an overview of coordination mechanisms operating during performance, including monitoring, the use of action-based communication, and mutual action prediction. Finally, we outline opportunities lying ahead of us in the field of joint-action research.

Preparing for Joint Action

Studying processes of action preparation that occur just before interaction partners begin to act together provides a window into joint action planning and can reveal ways in which other people's contributions are integrated in planning. The novel experimental approaches developed to study joint action preparation thus complement earlier philosophical work that focused on questions of long-term planning.

Forming representations of each other's actions

Studies using electroencephalography (EEG) have shown that during immediate preparation for joint action, coactors not only plan their own part but also represent their partner's upcoming actions in a similar way as if they were going to perform the other's part. For example, Kourtis and colleagues (2014) performed an EEG study in which participants were asked to clink glasses. The amplitude of the contingent negative variation (CNV), a component that reflects action planning, was measured during a preparation phase in which participants were getting ready to act together but were not moving yet. Generally, the CNV amplitude is higher when people are preparing to perform a bimanual action that requires coordination between their two hands, compared with performing a unimanual action. This fact provided the opportunity to investigate whether during joint action preparation, coactors plan only their own part of the joint action or whether they plan both parts. If planning only their own part, the coactors' CNV amplitude should resemble the amplitude associated with unimanual action preparation. If planning both parts, the coactors' CNV amplitude should resemble the amplitude associated with bimanual action preparation even though participants are using only one hand during joint action. The results showed a striking similarity in motor preparation for joint and bimanual coordination, suggesting that coactors represented their task partner's contribution in a similar way as their own (Vesper et al., 2013).

Further studies have shown that people also represent constraints on others' task performance, such as an obstacle that is in a task partner's way (Schmitz et al., 2017). Schmitz and colleagues asked pairs of participants to move one object each to a target position while an obstacle sometimes blocked the direct movement path of one but not the other coactor. They found that the coactor who did not have an obstacle in their way lifted their own arms higher compared with their partner who did not have an obstacle in their way. Importantly, the effect of the partner's obstacle on movement height did not depend on observation of the partner's actions and was present when participants merely knew about the obstacle being in their partner's way. When coactors were instructed to coordinate their actions so that they would arrive at the target locations at the same time, the effect of the other's obstacle increased. This demonstrates that when people are trying to coordinate, they are more likely to represent specifics of the partner's actions.

In addition to representing single actions, joint-action partners also represent other aspects of each other's tasks, such as the order in which actions are to be performed. Schmitz and colleagues (2018) asked pairs of participants to move to targets arranged either in the same order (e.g., both moving to a red target and then to a blue target) or in the opposite order (one moving from red to blue, the other from blue to red). Regardless of movement parameters, participants were slower when performing opposite sequences, suggesting that they represented their partner's order of actions even though this was not necessary for performing the joint task and impaired performance. Interference between tasks (Böckler et al., 2012) and actions (Sebanz et al., 2003) was also observed in experiments in which coordination was not required beyond taking turns in performing tasks. It would be a mistake to conclude on the basis of these findings that representing other people's actions and tasks is not beneficial. In most everyday joint actions, coactors perform similar or complementary rather than opposite actions. Using opposite actions and tasks is an experimental technique to demonstrate the occurrence of action and task co-representation. What the studies showing interference demonstrate is that people have a strong default to form representations of others' tasks and actions, so much so that they do this even outside of typical joint-action contexts.

Representing relations between actions

As shown by Sacheli and colleagues (2018), representations of joint-action outcomes can eliminate interference between individual actions. In their study, participants performed a series of grasping and pointing movements to produce a melody. When pairs of participants acted independently without the goal of producing a melody together, their movements interfered with each other. However, when the same movements were made to jointly produce a melody, there was no longer any movement interference.

Recent findings by Kourtis and colleagues (2019) also suggest that forming representations that specify relations between one's own and others' actions can help with coordination. Using a game that involved performing different hand shapes together, they provided participants with cues that did or did not specify the upcoming actions or informed participants only about the relation between their actions (whether they would perform the same or a different action). Not surprisingly, motor preparation occurred in response to cues specifying participants' upcoming actions and facilitated performance. However, evidence for motor preparation was found even when partners received only abstract information about the relation between their actions. Even though they did not know which specific action to prepare for, knowing whether they would be performing the same or a different action sped up their subsequent performance and resulted in better coordination compared with not having advance information about the relation between the actions. This indicates that coordination not only benefits from interaction partners representing each other's specific tasks and actions but also is guided by representations of relations between actions.

Joint task representations can also facilitate imitation (Tsai et al., 2011) and the learning of joint actions from observing other people. To illustrate, when we want to learn how to tango, we need to learn not only individual steps but also how to recreate the observed spatial and temporal relations between the two partners' actions. Therefore, having the opportunity to observe the relations between two partners' actions may provide more guidance for how to perform the observed actions with a partner, compared with observing the same actions performed by a single individual. This prediction was tested in a study in which pairs of participants were asked to synchronize their hand movements with observed actions that were performed either by a single individual using two hands or by two individuals using one hand each (Ramenzoni et al., 2014). The observed hand movements were otherwise identical. Pairs of participants were indeed better at performing the observed actions when these were demonstrated by two individuals, reflected in higher accuracy in matching their hand movements spatially and temporally with the observed movements.

Achieving Coordination During Joint Action Performance

People's propensity to form joint task representations allows them to start performing joint actions well prepared, but this is not sufficient to ensure successful coordination. This is especially so for joint actions that require coactors to achieve and maintain a high degree of spatial and temporal coordination of individual contributions. Recent research on joint action has demonstrated that coordination during joint performance involves integrating information specified in representations of the joint task with the available perceptual information.

Action monitoring

Coactors starting from a well-specified representation of the joint task and the individual contributions required need to ensure that their ongoing joint performance goes according to plan. This can be achieved by monitoring errors in the coactor's own actions, in others' individual actions, and in joint outcomes. In an EEG study on piano experts performing duets, Loehr and colleagues (2013) demonstrated that there is parallel and separate monitoring of individual contributions and of joint outcomes. While one pianist played the treble part of a piece as another pianist played the bass part, they heard errors in their own part or the other's part. These errors did or did not affect the joint harmony. Whereas potentials related to early error detection showed the same response to all kinds of errors, potentials related to conscious recognition of performance violations were larger for errors affecting the jointly produced harmony compared with errors in individual parts. Pianists also showed a larger response to errors in their own part compared with errors in the other's part, demonstrating that in terms of conscious recognition and evaluation, one's own performance and joint outcomes are prioritized.

Predicting partners' performance

To coordinate, coactors can simulate and thus predict a coactor's performance not only on the basis of representations of the prescribed joint-action outcome (e.g., sheet music) but also on the basis of being familiar with the coactor's individual performance. Wolf and colleagues (2018) addressed this type of coordination in a study in which piano teachers were asked to play duets with beginners. Performance of the joint duet was more successful if the piano teachers had previously heard how the beginners performed their part of the duet. Picking up on idiosyncratic temporal patterns in the beginners' performance during a familiarization phase enabled teachers to immediately adapt to achieve more precise temporal coordination with the beginner. Experts presumably achieved this by adjusting the timing of their own actions on the basis of predictions about the beginners' timing of upcoming actions.

Action-based communication

However, joint actions do not always follow a well-defined score that specifies individual actions and their relations, as in classical music performance, choreographed dance performances, or fixed rituals. Rather, initial task representations may be incomplete and create knowledge asymmetries between different coactors. If only one coactor knows the goal of a joint action or certain aspects of the joint action, it is crucial for the coactor to inform his or her partner. One solution is to verbally communicate (Clark, 1996). However, sometimes verbal communication is not feasible, as in noisy environments or when the verbal communication channel is occupied. Verbal communication may also be too slow to inform the partner in time, or the required information may be hard to put into words. For instance, it would be difficult for a basketball player to describe for a teammate the exact position and time of the ball after a pass.

Pezzulo et al. (2013) proposed that there is another way to inform coactors about important aspects of a joint task: In action-based communication, modulating or exaggerating certain parameters of an instrumental action during performance makes it possible to provide information to a coactor. For instance, if only one coactor knows the target location of a joint aiming action, the coactor can communicate the location by deviating from the straight path to highlight the target position. The beauty of Pezzulo and colleagues' proposal is that it provides a very general framework about how instrumental actions can take on a communicative function: Any systematic deviation from the most efficient way to perform a movement can be used to inform coactors. By now, there is ample empirical evidence that joint-action partners frequently and flexibly use action-based communication. For instance, it has been demonstrated that movement duration is modulated to communicate the distance of a target (Vesper et al., 2017) and that modulations of movement height and modulations of velocity parameters can effectively inform coactors about target positions in a movement sequence (McEllin et al., 2018).

Movement parameters are not just modulated or exaggerated to inform a coactor about unknown aspects of a joint task. These modulations can also help with improving temporal and spatial coordination. Vesper and colleagues (2016) demonstrated that coactors performing a task that required reaching the same region in space at the same time successfully modulated the amplitude of their movements to make individual arrival times more predictable. These modulations occurred only if coactors could see each other's movements. If coactors could not observe each other's movements, they achieved coordination by always moving in the same way, thereby reducing variability and making individual arrival times more predictable. Thus, coactors are highly flexible in how they achieve joint action coordination depending on the available information.

Coupled predictors

When coactors have ample perceptual information about the actions they perform, reciprocal flow of information between two actors can be sufficient to enable effective joint action coordination without a prespecified task representation. Accordingly, Noy and colleagues (2011) proposed that successful joint improvisation relies on reciprocal information flow between the improvisers. They studied performance in an adapted mirror-game exercise in which two players need to synchronize their actions without prespecified movement patterns. Improvisation experts, but not beginners, were able to achieve smooth coordination by using bidirectional information flow to predict each other's actions. Whereas Noy and colleagues found that coordination was impaired when one player acted as a leader and the other as a follower, work by Richardson and colleagues (2015) showed that effective role distribution between two coactors can spontaneously emerge.

Using a joint-action task that required coactors to trade off the spatial and temporal accuracy of coordination, Curioni and colleagues (2019) found that coordination was equally effective when two coactors could see and mutually predict each other's actions, such as when they acted as a leader and follower in a situation in which only one could see the other. However, coordination deteriorated when assigned roles conflicted with the availability of bidirectional information flow. This indicates that successful coordination can be achieved in more than one way but suffers when there is ambiguity on how to coordinate.

Conclusions

Joint-action research has gained a lot of popularity in recent years and has improved our understanding of how people achieve and maintain coordination while preparing and performing joint actions. To better understand the implications of the findings obtained so far, joint-action researchers should seek closer connections to other fields in psychology that address social interaction. Fundamental questions that arise in relation to comparative research is which human abilities to perform joint actions are shared with other species and what their evolutionary roots may be. Joint action abilities in great apes, our evolutionary ancestors, may have driven the evolution of communication as a way to achieve enhanced abilities to pursue joint action goals (Voinov et al., 2020).

A further important goal for future research is to achieve a better understanding of how individuals decide whether to engage in joint action given the implicit and explicit commitments it entails (Michael et al., 2016) and the individual and joint costs that are involved (Török et al., 2019). Answering this question will require going beyond collective decisions (Roberts & Goldstone, 2011) and judgments about perceptual features (Bahrami et al., 2010) to understand how joint-action partners choose a course of joint action in the face of asymmetries in perception, knowledge, and abilities (Voinov et al., 2019). Addressing decision-making in the context of joint action also has the potential to create synergies between the research reviewed here and earlier work addressing joint action from a normative and communicative perspective.

Recommended Reading

El Zein, M., Bahrami, B., & Hertwig, R. (2019). Shared responsibility in collective decisions. *Nature Human Behavior*, *3*(6), 554–559. An overview of motivational and cognitive processes involved in joint decision-making.

Hasson, U., & Frith, C. D. (2016). Mirroring and beyond: Coupled dynamics as a generalized framework for modelling social interactions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1693), Article 20150366. https://doi.org/10.1098/rstb.2015.0366. A review article discussing the role of shared brain activity in social interaction.

Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action: Theory and data. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 54, pp. 59–101). Academic Press. An overview of studies addressing the perceptual, cognitive, and motor processes involved in planning and coordinating joint actions.

Michael, J., & Pacherie, E. (2015). (See References). A theoretical article linking philosophical and psychological concepts in joint-action research.

Milward, S. J., & Carpenter, M. (2018). Joint action and joint attention: Drawing parallels between the literatures. *Social and Personality Psychology Compass*, *12*(4), Article e12377. https://doi.org/10.1111/spc3.12377. An overview elucidating links between research on joint action and joint attention focusing on different notions of jointness.

Transparency

Action Editor: Robert L. Goldstone
Editor: Robert L. Goldstone
Declaration of Conflicting Interests
The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.
Funding
This work was supported by the European Research Council (ERC) under the European Union's Seventh Framework Programme (FP7/2007–2013)/ERC Grant No. 609819, SOMICS, and by ERC Grant No. 616072, JAXPERTISE.

ORCID iD

Natalie Sebanz https://orcid.org/0000-0003-1280-8974

References

Bahrami, B., Olsen, K., Latham, P. E., Roepstorff, A., Rees, G., & Frith, C. D. (2010). Optimally interacting minds. *Science*, *329*(5995), 1081–1085.

Böckler, A., Knoblich, G., & Sebanz, N. (2012). Effects of a coactor's focus of attention on task performance. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(6), 1404–1415.

Bratman, M. E. (2014). *Shared agency: A planning theory of acting together*. Oxford University Press.

Brennan, S. E., Kuhlen, A. K., & Charoy, J. (2018). Discourse and dialogue. In J. T. Wixted (Series Ed.) & S. Thompson-Schill (Volume Ed.), *Stevens' handbook of experimental psychology and cognitive neuroscience* (Vol. 3). Wiley. https://doi.org/10.1002/9781119170174.epcn305

Clark, H. H. (1996). *Using language*. Cambridge University Press.

Curioni, A., Vesper, C., Knoblich, G., & Sebanz, N. (2019). Reciprocal information flow and role distribution support joint action coordination. *Cognition*, *187*, 21–31.

D'Ausilio, A., Novembre, G., Fadiga, L., & Keller, P. E. (2015). What can music tell us about social interaction? *Trends in Cognitive Sciences*, *19*, 111–114.

Jouravlev, O., Schwartz, R., Ayyash, D., Mineroff, Z., Gibson, E., & Fedorenko, E. (2019). Tracking colisteners' knowledge states during language comprehension. *Psychological Science*, *30*(1), 3–19.

Kourtis, D., Knoblich, G., Wozniak, M., & Sebanz, N. (2014). Attention allocation and task representation during joint action planning. *Journal of Cognitive Neuroscience*, *26*(10), 2275–2286.

Kourtis, D., Woźniak, M., Sebanz, N., & Knoblich, G. (2019). Evidence for we-representations during joint action planning. *Neuropsychologia*, *131*, 73–83.

Loehr, J. D., Kourtis, D., Vesper, C., Sebanz, N., & Knoblich, G. (2013). Monitoring individual and joint action outcomes in duet music performance. *Journal of Cognitive Neuroscience*, *25*, 1049–1061.

McEllin, L., Knoblich, G., & Sebanz, N. (2018). Distinct kinematic markers of demonstration and joint action coordination? Evidence from virtual xylophone playing. *Journal of Experimental Psychology: Human Perception and Performance*, *44*(6), 885–897.

Michael, J., & Pacherie, E. (2015). On commitments and other uncertainty reduction tools in joint action. *Journal of Social Ontology*, *1*(1), 89–120.

Michael, J., Sebanz, N., & Knoblich, G. (2016). The sense of commitment: A minimal approach. *Frontiers in Psychology*, *6*, Article 1968. https://doi.org/10.3389/fpsyg.2015.01968

Noy, L., Dekel, E., & Alon, U. (2011). The mirror game as a paradigm for studying the dynamics of two people improvising motion together. *Proceedings of the National Academy of Sciences, USA*, *108*(52), 20947–20952.

Pezzulo, G., Donnarumma, F., & Dindo, H. (2013). Human sensorimotor communication: A theory of signaling in online interactions. *PLOS ONE*, *8*(11), Article e79876. https://doi.org/10.1371/journal.pone.0079876

Ramenzoni, V., Sebanz, N., & Knoblich, G. (2014). Scaling-up perception-action links: Evidence from synchronization with individual and joint action. *Journal of Experimental Psychology: Human Perception and Performance*, *40*, 1551–1565.

Richardson, M. J., Harrison, S. J., Kallen, R. W., Walton, A., Eiler, B. A., Saltzman, E., & Schmidt, R. C. (2015). Self-organized complementary joint action: Behavioral dynamics of an interpersonal collision-avoidance task. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(3), 665–679.

Roberts, M. E., & Goldstone, R. L. (2011). Adaptive group coordination and role differentiation. *PLOS ONE*, *6*(7), Article e22377. https://doi.org/10.1371/journal.pone.0022377

Sacheli, L. M., Arcangeli, E., & Paulesu, E. (2018). Evidence for a dyadic motor plan in joint action. *Scientific Reports*, *8*, Article 5027. https://doi.org/10.1038/s41598-018-23275-9

Schmidt, R. C., & Richardson, M. J. (2008). Dynamics of interpersonal coordination. In A. Fuchs & V. K. Jirsa (Eds.), *Coordination: Neural, behavioral and social dynamics* (pp. 281–308). Springer.

Schmitz, L., Vesper, C., Sebanz, N., & Knoblich, G. (2017). Co-representation of others' task constraints in joint action. *Journal of Experimental Psychology. Human Perception and Performance*, *43*(8), 1480–1493.

Schmitz, L., Vesper, C., Sebanz, N., & Knoblich, G. (2018). Co-actors represent the order of each other's actions. *Cognition*, *181*, 65–79.

Sebanz, N., Knoblich, G., & Prinz, W. (2003). Representing others' actions: Just like one's own? *Cognition*, *88*(3), B11–B21.

Thomaz, A., Hoffman, G., & Cakmak, M. (2016). Computational human-robot interaction. *Foundations and Trends in Robotics*, *4*(2–3), 104–223.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences*, *28*(5), 675–691.

Török, G., Pomiechowska, B., Csibra, G., & Sebanz, N. (2019). Rationality in joint action: Maximizing coefficiency in coordination. *Psychological Science*, *30*(6), 930–941.

Tsai, C., Sebanz, N., & Knoblich, G. (2011). The GROOP effect: Groups mimic group actions. *Cognition*, *118*, 135–140.

Vesper, C., Schmitz, L., & Knoblich, G. (2017). Modulating action duration to establish non-conventional communication. *Journal of Experimental Psychology: General*, *146*, 1722–1737.

Vesper, C., Schmitz, L., Safra, L., Sebanz, N., & Knoblich, G. (2016). The role of shared visual information for joint action coordination. *Cognition*, *153*, 118–123.

Vesper, C., van der Wel, P. R. D., Knoblich, G., & Sebanz, N. (2013). Are you ready to jump? Predictive mechanisms in interpersonal coordination. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(1), 48–61.

Voinov, P. V., Call, J., Knoblich, G., Oshkina, M., & Allritz, M. (2020). Chimpanzee coordination and potential communication in a two-touchscreen turn-taking game. *Scientific Reports*, *10*, Article 3400. https://doi.org/10.1038/s41598-020-60307-9

Voinov, P. V., Sebanz, N., & Knoblich, G. (2019). Collective benefit in joint perceptual judgments: Partial roles of shared environments, meta-cognition, and feedback. *Cognition*, *189*, 116–130.

Wolf, T., Sebanz, N., & Knoblich, G. (2018). Joint action coordination in expert-novice pairs: Can experts predict novices' suboptimal timing? *Cognition*, *178*, 103–108.