Cognition 161 (2017) 60–65

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Brief article

The predictability of a partner's actions modulates the sense of joint agency

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ARTICLE INFO

Article history:
Received 23 June 2016
Revised 4 January 2017
Accepted 7 January 2017
Available online 19 January 2017

Keywords:
Agency
Joint action
Interpersonal coordination
Joint agency
Action prediction

ABSTRACT

When people coordinate their actions with others, they experience a sense of joint agency, i.e., shared control over actions and their consequences. The current study examined whether the predictability of others' actions modulates joint agency. Each participant coordinated with two confederate partners to produce tone sequences that matched a metronome pace. The timing of the confederates' actions was manipulated so that one partner's actions were highly predictable in time and the other's less predictable. After each sequence, participants rated their experience of joint agency on a scale from shared to independent control. People felt more shared control when they coordinated with the more predictable partner, even after controlling for their own performance accuracy and variability. Thus, people rely on predictions of others' actions to derive a sense of joint agency during interpersonal coordination.

1. Introduction

When people perform actions, they experience a *sense of agency*, i.e., control over actions and their consequences (Haggard & Tsakiris, 2009). Considerable research has established that predictive mechanisms play a critical role in the sense of agency (Haggard & Eitam, 2015; Synofzik, Vosgerau, & Voss, 2013). However, this research has focused almost exclusively on people performing actions alone. Little research has examined the sense of agency when people perform joint actions, i.e., coordinate their actions with others to achieve a shared goal (Sebanz, Bekkering, & Knoblich, 2006). Joint actions raise interesting questions about agency because they require people to make predictions about not only their own but also their co-performers' actions (Vesper, Butterfill, Knoblich, & Sebanz, 2010). Philosophers have proposed that people may experience a sense of *joint agency*, or shared control over actions and effects, during joint action (Dokic, 2010; Pacherie, 2012; Seemann, 2009) and that joint agency may be driven in part by people's ability to predict their co-performers' actions (Pacherie, 2012). The current study presents the first direct empirical investigation of this hypothesis.

Experiences of agency during solo action (*self-agency*) depend on comparisons between prior predictions and post hoc information about actions (Synofzik et al., 2013), at multiple levels of action specification (Pacherie, 2008). The closer the match between the predicted and actual consequences of an action, the stronger the sense of self-agency. At the sensorimotor level, internal predictions about the sensory consequences of actions, generated from efference copies of motor commands, are compared with actual sensory consequences (Frith, Blakemore, & Wolpert, 2000). At the perceptual level, self-agency relies in part on contiguity between actions and perceptual consequences. For example, introducing delays between taps and the tones they elicit reduces self-agency (Sato & Yasuda, 2005). Recent models of self-agency emphasize that cues at each level are weighted differently depending on their availability and reliability (Moore & Fletcher, 2012; Synofzik et al., 2013).

Successful joint action requires people to make predictions not only about their own actions (*self-predictions*), but also about their partners' actions (*other-predictions*) and the joint action (*joint-predictions*; Pacherie, 2012). During joint action, people predict the consequences of others' actions (Kourtis, Sebanz, & Knoblich, 2013; Loehr, Kourtis, Vesper, Sebanz, & Knoblich, 2013) and integrate simulations of different parts of the joint action (Vesper, Knoblich, & Sebanz, 2014). Thus, they are able to compare other- and joint-predictions with actual outcomes (Keller, Novembre, & Loehr, 2016; Wolpert, Doya, & Kawato, 2003). Because people have access to perceptual but not sensory reafferent information about their partners' actions, perceptual predictions likely have a greater role than sensorimotor predictions in the experience of agency during joint action (Pacherie, 2012; van der Wel & Knoblich, 2013).

Pacherie (2012) proposed that the sense of joint agency depends on the accuracy of self-, other-, and joint-predictions. Indirect support for this account comes from findings that ratings

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http://dx.doi.org/10.1016/j.cognition.2017.01.004
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of control over a joint action are positively correlated with the smoothness of both one's own and a partner's movements (van der Wel, 2015) and with pair-level task accuracy (Dewey, Pacherie, & Knoblich, 2014; van der Wel, Sebanz, & Knoblich, 2012). However, the rating scales used in these studies were ambiguous as to whether they referred to self-agency, joint agency, or both (Dewey et al., 2014). When people are specifically asked to rate joint agency, factors that increase coordination between partners increase the strength of joint agency (Bolt, Poncelet, Schultz, & Loehr, 2016). This also indirectly supports Pacherie's (2012) proposal, because the better people are able to predict their partners' actions, the better coordinated they are (Keller, Knoblich, & Repp, 2007; Loehr & Palmer, 2011). The current study sought to provide direct evidence for the hypothesis that joint agency depends on the accuracy of other-predictions. We asked participants to rate their feelings of joint agency after coordinating with two partners, the timing of whose actions we manipulated so that one partner's actions were highly predictable in time and the other partner's less predictable. We expected that people would experience stronger joint agency when they coordinated with the more predictable partner. Alternatively, if joint agency is driven primarily by sensorimotor predictions about one's own actions, then partner predictability should have little effect on joint agency.

2. Method

2.1. Participants

Forty-eight adults (17 male, M_{age} = 19.69, SD = 2.18) participated in the study. Ethical approval was obtained from the institutional review board. Participants gave informed consent and were compensated with course credit.

2.2. Design

Participants coordinated their actions with confederate partners[1] to produce 8-tone sequences that matched a metronome pace (Fig. 1). Partner predictability was manipulated within-subjects. Each participant was paired with a *high-predictability* and a *low-predictability* partner. The partners' inter-tone intervals (ITIs) were selected from uniform distributions that ranged in 1 ms increments from 490 to 510 ms (i.e., the 500 ms metronome pace ± 10 ms) and 440 to 560 ms (500 ± 60 ms), respectively.

2.3. Procedure

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

Partners sat on the same side of a table with a computer screen centered between them ~60 cm from the table edge. An Interlink force-sensitive resister (FSR; 3.81 cm^2) was placed in front of each partner ~30 cm from table edge. Only the participant's FSR was operational. Participants tapped the FSR with the index finger of their dominant hand. The FSR registered taps without providing auditory feedback. Each tap triggered a 1000 Hz tone (100 ms duration, 10 ms rise/fall) via a WaveShield connected to an Arduino microcontroller, ensuring an ~3 ms tap-to-tone latency (Schultz & van Vugt, 2015). The Arduinos signaled PsychoPy software (Peirce, 2007) when a tap was registered. PsychoPy recorded the taps and presented the remaining stimuli, including the metronome (880 Hz) and confederate (1000 Hz) tones. Tones were presented through speakers on both sides of the screen. Number keypads were placed beside each FSR and a 40 cm occluder was centered between the FSRs to prevent partners from seeing each other's taps and ratings.

Each half of the experiment began with two trials during which the experimenter explained the task. Partners then performed 5 training trials and 6 blocks of 5 test trials. Both partners provided agency ratings after every test trial. One partner was the leader (produced the first sequence tone) for all trials in a block. Partners alternated between leader and follower across blocks (including training). We counterbalanced whether the participant was the leader on the first block across participants.[2] At the beginning of each block, instructions presented onscreen indicated which partner was the leader.

Each trial began with a 2000 ms visual cue that reminded participants who was the leader. A fixation cross then appeared and remained in the center of the screen until the last sequence tone was produced. Four metronome tones were presented at 500 ms intervals beginning 500 ms after fixation onset. Partners were instructed to alternate their actions to produce an 8-tone sequence while maintaining the metronome pace. Confederates produced tapping movements that did not contact the FSR. After each sequence, both partners rated their "feelings of control over the timing of the sequence" on a scale from 01 ("shared control") to 99 ("independent control"). Scale endpoints were chosen based on philosophical definitions of joint agency (see Bolt et al., 2016). Zero was included as the first digit for ratings <10 to prevent partners from guessing each other's ratings based on number of keystrokes. Partners entered their ratings in random order, determined separately for each trial and signaled by which side of the screen the rating instructions appeared on first.

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

2.4. Data analysis

2.4.1. Errors

Trials with rating errors (partners entered their ratings in the wrong order or an invalid rating of 0 or >99; 2.2%) were excluded from analysis. Trials with sequence errors were also excluded from analysis. Because the computer produced a confederate tone after each of the participant's taps and/or the last pacing tone, the correct sequence was always produced. Sequence errors were therefore identified by unusually short or long ITIs (3*SD* above or

[1] None of the participants knew either confederate before the experiment.

[2] Because leader/follower roles have little influence on joint agency in the coordination task used here (see Bolt et al., 2016), we counterbalanced role but did not analyze its influence further.