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Me and we: Metacognition and performance evaluation of joint actions

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ABSTRACT

Recent evidence suggests the existence of we-mode processing, but little is still known about how such processing influences the sense of control during intentional joint actions. To examine this issue, dyads performed a video game in which they moved a dot to the target of their choice out of a set of targets. By having each participant control the dot movements in only one dimension (orthogonal to their partner) and by varying the target locations, participants took on different roles. By chance, they also could have congruent or incongruent intentions prior to the movements. In a decider–follower scenario, where one actor decided on the target, judgments of control and judgments of performance depended on whether a prior intention was instantiated, but not on actor role. This finding is consistent with we-mode processing. When participants had conflicting intentions that needed to be resolved online, both the dominant and the nondominant participant showed a marked reduction in the perceived quality of the performance. Thus, dynamic intention negotiation reduced we-mode processing and shifted it toward I-mode processing. The nondominant actor also reported a strongly reduced sense of control. Implications for theories on the sense of agency and for applied settings are discussed.

1. Introduction

As intentional agents, we feel in control over most of our actions. Nonetheless, people may experience a sense of agency over action effects they did not cause, or they may fail to experience a sense of agency over action effects they did cause (see van der Wel & Knoblich, 2013, for a recent review). This observation puts the sense of agency squarely in the realm of psychological theorizing.

The sense of agency consists of a multitude of aspects. It includes the sense that one initiated an action as well as the sense that one is in control over the action, amongst other aspects (see Haggard & Tsakiris, 2009; Pacherie, 2008). Here, I will focus specifically on the sense of control in the context of actions that are intentionally produced together with another actor (i.e., joint actions). For such actions, an important theoretical question is to what extent an actor's sense of control is derived from control at the group-level versus the actor's individual contributions.

Studying how people sense agency over joint actions is important for our theoretical understanding of intentional action, and for applied reasons. People often work in pairs or teams, and the extent to which all actors involved have an agentic experience may influence the objective outcome quality of joint collaborations (e.g., Babcock & Loewenstein, 1997). It may also influence the subjective perception of the outcome quality, and subsequently influence whether people continue to collaborate with one another altogether (e.g., Caruso, Epley, & Bazerman, 2006). The subjective experience of collaborations over extended time spans may in part be driven by such experiences over much shorter time spans. Thus, a better understanding of the

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experience of joint actions over relatively short durations may benefit theories of intentional action, but may also inform settings in which team performance is key, be it on a pitch or in an office.

Two main accounts have been developed for how a sense of agency over actions is established. There is growing consensus that these accounts are complementary rather than conflicting in nature. One is a predictive account (e.g. Blakemore, Wolpert, & Frith, 2002; Haggard, 2005; Tsakiris, Prabhu, & Haggard, 2006) and one is a postdictive account (Wegner, 2002). The predictive (sensorimotor) account postulates that the sense of agency arises based on the match between the predicted and actual sensory consequences of an action. The closer this match is, the stronger of a sense of agency people experience. Whereas the predictive account establishes the sense of agency dynamically during the action, the postdictive account assumes that the sense of agency is established after the action is completed. In particular, this account focuses on the presence of a prior intention, the consistency between the intended and actual action effect, and whether an alternative cause for the action effect is present (priority, consistency, and exclusivity, respectively).

Empirical studies on the sense of agency have found some support for both of these accounts. The core issue in these studies has been how ambiguities about the cause of an action effect influence the sense of agency. These studies addressed which factors reliably influence the sense of agency (e.g., Metcalfe & Greene, 2007), and how discrepancies between the intention, the action, and action effect influence the sense of agency (e.g., David, Newen, & Vogeley, 2008; Knoblich & Kircher, 2004; Knoblich & Repp, 2009; van den Bos & Jeannerod, 2002).

Joint actions provide a challenge for both the predictive and the postdictive account on the sense of agency. As actors in a joint action do not have access to the sensorimotor information of their co-actors, the matching between expected an actual sensorimotor signals that is central to the predictive account is not fully possible. Prediction may still take place at a perceptual level, but this raises the question how sensorimotor signals of one's own contribution and perceptual signals of the joint performance are integrated. From a postdictive account, exclusivity is intentionally absent for joint actions. How then do people derive a sense of control over joint actions?

The past decade has seen a surge of interest in research on joint actions. This research has revealed that people may automatically track others' tasks (e.g., Sebanz, Knoblich, & Prinz, 2005), perspectives (e.g., Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010), attentional focus (e.g., Böckler, Knoblich, & Sebanz, 2012), and beliefs (e.g., Kovács, Teglas, & Endress, 2010; van der Wel, Sebanz, & Knoblich, 2014). Group membership has also been shown to modulate perception–action links (Obhi & Hall, 2011a, 2011b; Tsai, Sebanz, & Knoblich, 2011; Weiss, Herwig, & Schütz-Bosbach, 2011). Based on such findings, Gallotti and Frith (2013) proposed the existence of a 'we-mode' that supports social interaction (see also Tuomela, 2005; Tuomela, 2006).

The presence of a we-mode raises the question whether we-mode processing influences the sense of control over joint actions. Actors may represent co-actors during a joint action, but this need not imply that we-mode processing influences the sense of control experienced by the individuals involved in the joint action. Here, I tested whether and when metacognitive assessments of control (i.e., whether people are able to monitor their own agency, Metcalfe & Greene, 2007) and performance evaluations reflect we-mode processing when people engage in joint actions.

One previous study has examined the role of we-mode processing on the sense of control for joint actions (Dewey, Pacherie, & Knnoblich, 2014). In their study, two participants controlled the movements of a dot to track a moving target on a computer screen by controlling one joystick each. When participants controlled overlapping dimensions of the dot movements (i.e., both controlling the horizontal dimension), participants' ratings of control were most consistent with egocentric processing, and the co-actor's movements were essentially treated as a perturbation. In contrast, when participants had complementary roles (i.e., one controlling movements to the left and one controlling movements to the right), the results appeared to be consistent with we-mode processing. In particular, participants reported a stronger sense of control when their co-actor controlled the complementary dimension versus when the computer did. However, the results of the critical experiments in Dewey et al. (Experiments 2 and 3) indicated differences in the objective quality of performance between the conditions that coincided with differences in the reported judgments of control (i.e., as error increased, judgments of control decreased). As such differences were not controlled for in their analyses (i.e., added as a random intercept in a mixed linear model), this study does not provide conclusive evidence for we-mode processing for the sense of control. In addition, the complementary task in Dewey et al. (2014) effectively involved a turn-taking task rather than a parallel joint action task. It thus remains to be seen whether we-mode processing underlies the sense of control for joint parallel actions, and under what circumstances.

Here, I examined when the sense of control depends on we-mode processing for tasks in which actors perform parallel complementary actions. Based on we-mode processing, performance of a joint action is evaluated at the level of the group instead of at the level of the individuals' particular contributions (to which I will refer as the I-mode, Tuomela, 2005). Thus, based on we-mode processing the sense of control and performance evaluation should not depend on the particular role an actor plays in a joint action (see Pacherie, 2013). In the case of rowing, the coxswain who is steering the boat and the rowers creating forward motion should have similar experiences of control, just as the surgical assistant and the surgeon should. In contrast, based on I-mode processing, actor role should influence the sense of control.

I also examined the relationships between objective performance, judgments of control, judgments of performance, and movement parameters of both the participant and the action partner to test for we-mode versus I-mode processing. In this respect, I-mode processing would predict correlations between an actor's own movement parameters and judgments of control, but not between a co-actor's movement parameters and the actor's own judgments of control. Based on we-mode processing, similar correlations between both one's own movement parameters as well as a co-actor's movement parameters and judgments of control would be predicted.

2. Methods

2.1. Participants

96 students (52 females and 44 males between the ages of 18 and 24) from Rutgers University – Camden participated as 48 pairs in the experiment in exchange for course credit. All participants were right-handed (Oldfield, 1971) and none reported any neurological deficits. All the recorded data were included. I tested 48 pairs to allow for complete counterbalancing, as well as to ensure appropriate statistical power.

2.2. Experimental procedure and setup

Pairs of participants played a video game in which they moved a red dot from the center of a computer screen to one of two targets that appeared simultaneously in a given trial. There were four possible target locations throughout the experiment, one in each of the four quadrants of the screen. Participants moved the red dot by controlling a joystick, and the control was distributed in such a way that one actor controlled horizontal displacements (the horizontal controller) and one controlled vertical displacements (the vertical controller) of the dot. As moving to any of the targets required both horizontal and vertical displacement of the red dot, the horizontal and vertical controller had to work together. In addition, participants' action contributions were unambiguous as there was no dimensional overlap across the co-actors' contributions.

Fig. 1 shows the experimental setup and example layouts for each of the experimental conditions. Varying the locations of the two targets present in a given trial created different action roles for each actor across trials. For example, when the two targets appeared in the top-left and top-right quadrant of the screen, this implied that the horizontal controller decided which target to move to. Importantly, the vertical controller's contribution was still necessary in those trials, as the dot needed to be moved upwards by a fixed amount regardless of the horizontal controller's target choice. When the two targets

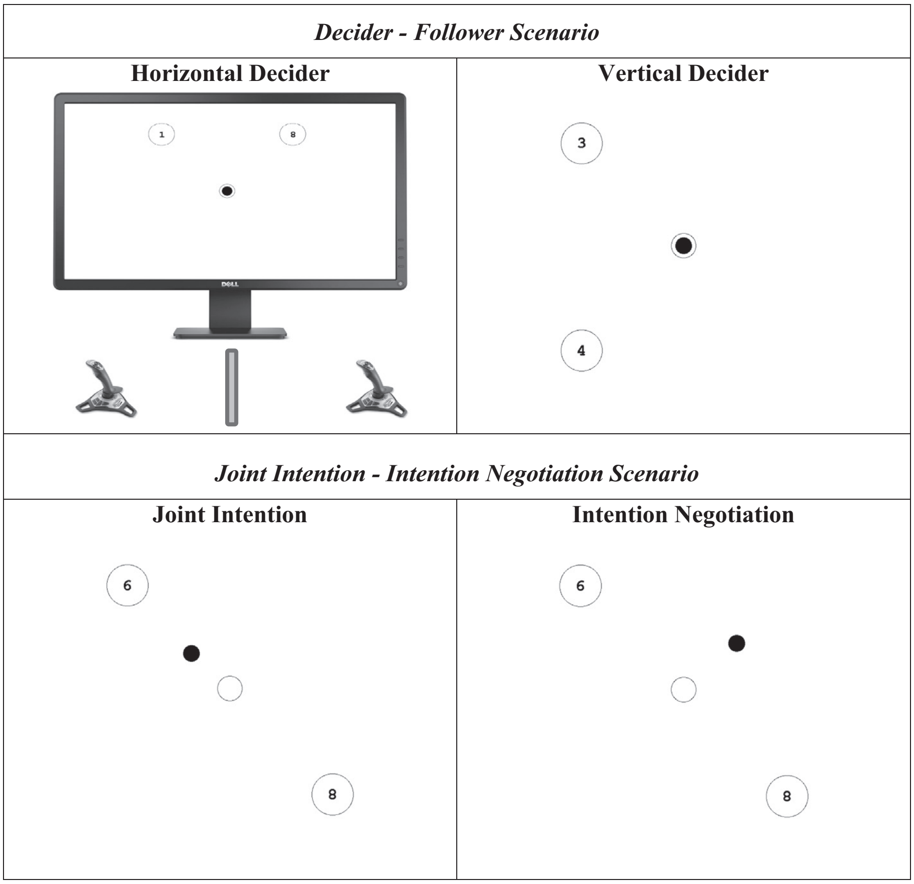

Fig. 1. Overview of the experimental conditions. The top left and right panels show Decider–Follower trials with the dot still in the start location. The bottom left and right panels show the Joint Intention–Intention negotiation scenario with the dot moving in a relevant movement direction. The numbers in the targets were only visible while participants indicated their intended target.

appeared on the same side of the screen (i.e., left-top and bottom, or right-top and bottom), the action roles reversed and the vertical controller determined which target to move to. I will refer to each of these cases of asymmetric trials as the decider–follower scenario.

The experiment also included trials in which the two targets appeared along one of the two diagonal axes of the screen. A priori, these trials implied symmetric action roles for the horizontal and vertical controller. If both controllers happened to intend to go to the same target, the actors effectively had a congruent joint intention and both controllers provided an equally causal contribution for reaching the target (joint intention scenario). However, when the two controllers happened to intend on going to the opposite target, they entered an intention negotiation situation (intention negotiation scenario). For example, if the two targets appeared on the main diagonal (top-left to bottom-right), an incongruent intention across controllers would result in dot displacement toward either the top-right or bottom-left. The controllers had to resolve this conflict online, implying that they would eventually move to the target intended by one of the two controllers only. Thus, one controller effectively became the dominant controller, and one controller became the nondominant controller in these cases.

Before each trial, each actor indicated to which target they intended to move (unbeknownst to the other actor) by entering the number that appeared in the target of their choice. They then completed the task as quickly as possible. After each trial, each actor provided judgment of control (JoC: "To what extent did you feel in control during the performance?") and a judgment of performance rating (JoPerf: "How well do you think you performed the task?"), both on a scale from 1 to 10. Ratings were provided through a computer keyboard, and actors did not have knowledge of each other's ratings. They had 5 s to provide each rating, and the experiment timed the full 5 s to discourage rapid responding.

Participants sat side by side behind a table, approximately 60 cm away and 40 cm sideways from the center of the screen. Each participant wore head-phones with white noise to prevent communication. They were separated by a room divider that ended 30 cm away from the screen. This positioning ensured that each participant could see the full screen without seeing each other. Each participant controlled a Logitec Attack 3 right-handed joystick positioned in a fixed position on the table at 30 cm away and 40 cm sideways from the center of the screen. These joysticks provided position data in the horizontal and vertical dimension at a rate of approximately 16 Hz. I used Matlab (The Mathworks, Natick, MA) with PsychToolbox (Brainard, 1997; Pelli, 1997) and a Dell Optiplex 7010 with a 22 inch monitor (resolution 1280×800 pixels) for running the experiment.

The start circle had a diameter of 60 pixels and appeared in the center of the screen. The red moving dot had a diameter of 40 pixels and a speed gain of 5 pixels. The targets were each 100 pixels in diameter, and their center was located 250 by 250 pixels from the center of the start location. The red dot needed to be completely inside a target circle to end the trial.

Participants had the opportunity to perform a practice trial to ensure their understanding of the instructions. In total, participants completed 72 trials. These trials were randomized in four blocks that each contained three instances of each of the six possible target combinations.

3. Results

Here, I report the results separately for each scenario (Decider–Follower and Joint Intention–Intention Negotiation) first, and then provide cross-scenario comparisons. Most of the reported results rely on mixed linear modeling, to account for differences in judgments of control and judgments of performance that are due to differences in task completion times across participants and conditions. For these tests, I report beta coefficients, standard error estimates, and estimated *t*-values, for which *t*s greater than 2 indicate conventional statistical significance.

Trials that took longer than 10 s to complete were removed from the data (2.6% of trials). Reported correlations were calculated within a participant, and only if the participant had at least three data points for the particular condition. For calculating correlations with movement smoothness, I first filtered the movement data with a low-pass Butterworth filter with a cutoff frequency of 8 Hz to remove noise from the data. I then calculated the ratio of 1 over the number of velocity peaks for the movements in the x and y dimension to determine movement smoothness for each actor in each trial. Thus, the higher the number of velocity peaks, the less smooth the movement was. Fig. 2 displays representative movement trajectories for the different scenarios.

3.1. Decider–Follower Scenario

First, I sought to determine how the actors' roles and the congruency of the actors' intentions influenced JoC and JoPerf. For each dependent variable, I conducted a mixed linear model analysis with Actor Role (decider/follower) and Congruency (congruent/incongruent intentions between actors) as fixed factors, and Task Completion Times as a random factor. It is important to note here that although the decider and follower could have incongruent intentions, the decider had no way of knowing this (as the target they moved to was always congruent with the decider's intention). Followers did become aware of the intention congruency, as they saw whether the decider moved to the target the follower would have chosen. It is also important to note that the follower's intention could be thought of as a preference rather than a strict intention, as one cannot rationally intend on something one cannot actually control (Pacherie, 2013).

Fig. 3 (left panel) shows the results for JoC. The analysis on JoC indicated an effect of Congruency ($b = 0.57$, $SE = 0.12$, $t = 4.57$), but not of Actor Role ($b = 0.22$, $SE = 0.28$, $t = 0.79$). The interaction also did not reach significance, ($b = -0.15$, $SE = 0.16$, $t = -0.92$). The analysis of JoPerf (Fig. 3, right panel) yielded similar results, with an effect of Congruency ($b = 0.32$, $SE = 0.09$, $t = 3.74$), but not

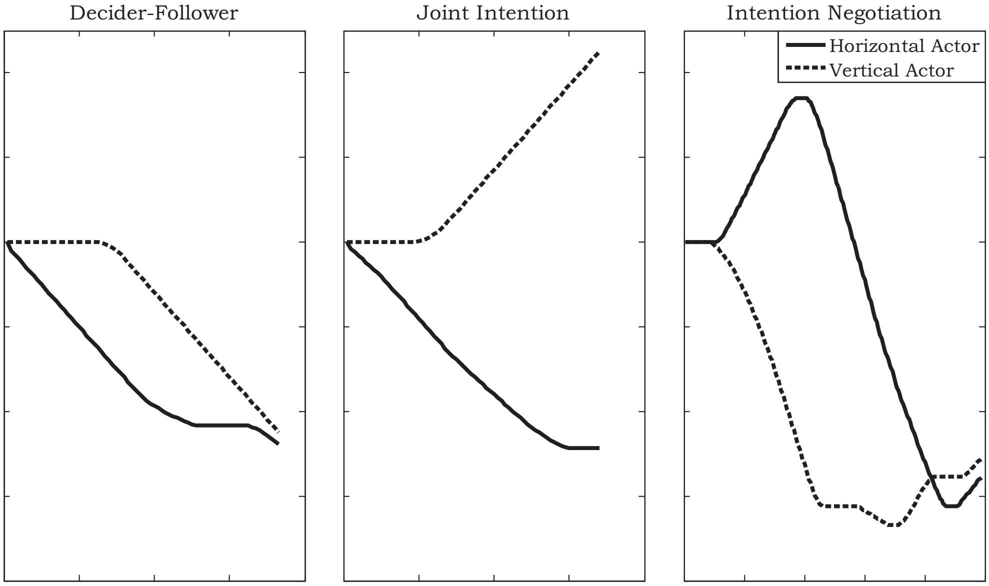

Fig. 2. Example trajectories for each of the possible situations. The *y*-axis represents position and the *x*-axis represents time. The decider–follower and joint intention cases show examples for when a target was in the bottom left (decider–follower panel) or bottom right (joint intention panel). In the intention negotiation panel, the change in movement direction by the horizontal actor corresponds to the negotiation being resolved.

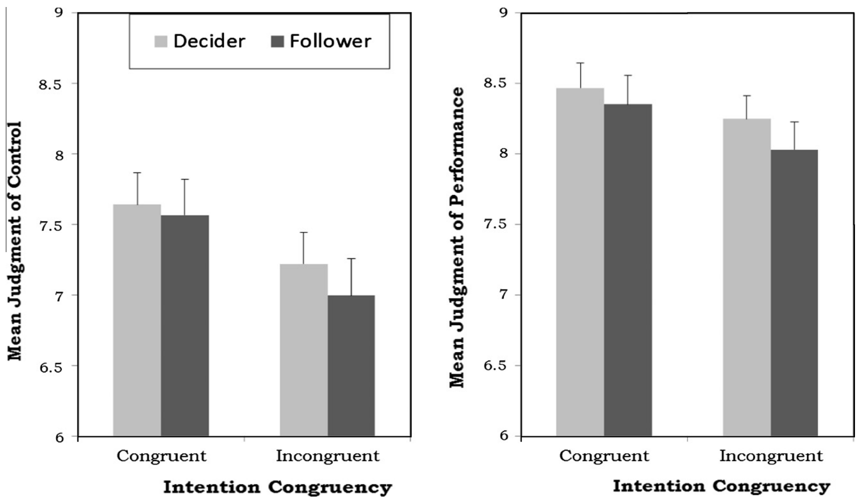

Fig. 3. Mean judgments of control ratings (left panel) and judgments of performance ratings (right panel) with standard error bars for the Decider–Follower scenario.

Actor Role ($b = 0.22$, $SE = 0.19$, $t = 1.18$), or an interaction ($b = -0.10$, $SE = 0.13$, $t = -0.81$). The absence of an effect of Actor Role is consistent with we-mode processing.

I also tested for differences in the strength of the correlations between JoC, JoPerf, and task completion times across conditions. First, I tested each of these correlations against zero. The analysis indicated significant relationships between each of the variables, regardless of actor's role and congruency (all *ps* <.01). Thus, in each case JoC and JoPerf increased as task completion times decreases. In addition, JoC increased with an increase in JoPerf.

To allow for comparisons across conditions, I then performed a Fisher-z transform (Fisher, 1921) on these correlations. The backtransformed average correlations per condition (Silver & Dunlap, 1987) are displayed in Table 1. I subjected the resulting values to a 2 (Actor Role) × 2 (Congruency) repeated-measures ANOVA, and did so for each pairing of the correlated variables. None of the three resulting analyses (JoC with JoPerf, JoC with task completion times, and JoPerf with task completion times) revealed significant main effects or interactions ($p > .10$). Thus, the relationships between JoC, JoPerf, and task completion times were present in all conditions, but

Table 1
Pearson correlations between judgments of control (JoCs), judgments of performance (JoPerfs), and task completion times (TCTs) for the Decider–Follower scenario.

	Pearson correlation *r* (SE)		
	JoCs/JoPerfs	JoCs/TCTs	JoPerfs/TCTs
Decider			
Congruent	0.53(0.08)	−0.27(0.05)	−0.48(0.05)
Incongruent	0.80(.24)	−0.34(0.06)	−0.45(0.09)
Follower			
Congruent	0.80(0.34)	−0.18(0.05)	−0.45(0.05)
Incongruent	0.79(0.30)	−0.30(0.08)	−0.39(0.08)

Table 2
Pearson correlations between judgments of control (JoCs), judgments of performance (JoPerfs) and movement smoothness for the Decider–Follower scenario.

	Pearson correlation *r* (SE)			
	JoCs/movement smoothness		JoPerfs/movement smoothness	
	Own moves	Partner moves	Own moves	Partner moves
Decider				
Congruent	0.18(0.04)	0.15(0.05)	0.31(0.05)	0.34(0.05)
Incongruent	0.15(0.06)	0.27(0.06)	0.50(0.27)	0.35(0.06)
Follower				
Congruent	0.09(0.05)	0.06(0.05)	0.22(0.05)	0.25(0.05)
Incongruent	0.14(0.06)	0.15(0.05)	0.29(0.06)	0.47(0.27)

their strength did not systematically depend on Actor's Role or congruency. This finding is also consistent with we-mode processing.

It is of interest to link such measures to the movements themselves as well, for two reasons. First, based on I-mode processing one would expect correlations between one's own movement smoothness and JoCs, but not between the co-actor's movement smoothness and JoCs. Based on we-mode processing, both kinds of correlations would be expected. Second, the predictive account on the sense of agency suggests that an actor's own movement smoothness should closely link to judgments of control. However, if the predictive account extends to predictions at the perceptual level, movement smoothness of the co-actor's actions may feed into judgments of control as well. Thus, I analyzed how movement smoothness related to JoC and JoPerf for the decider and follower. First, I tested for differences in movement smoothness between the congruent and incongruent trials. To do so, I took the average movement smoothness of the decider's and follower's trajectory in each trial. A paired t-test indicated a trend for reduced movement smoothness during incongruent trials ($M = 0.40$, $SE = 0.01$) versus congruent trials ($M = 0.38$, $SE = 0.01$), $t(95) = 1.73$, $p = .09$. To ensure that such differences in movement smoothness did not account for the lack of an effect of Actor Role in JoCs and JoPerfs, I reran the mixed model analyses reported above by including the number of velocity peaks for the decider and follower as random factors. Doing so did not change the pattern of findings.

I then computed correlations between movement smoothness, JoC, and JoPerf separately for decider/follower trials and for congruent/incongruent trials. I also calculated how the smoothness of a decider's trajectory influenced the follower's experience, and vice versa. Table 2 shows the results. I tested the resulting correlations against zero. The results indicated significant correlations between movement smoothness and JoC for all conditions (all *ps* < .05), except for the follower congruent case. In that case, the relationship was not significant for either one's own movement smoothness or the co-actor's movement smoothness.

To further examine these correlations, I subjected them to a 2 (Actor role) × 2 (Congruency) × 2 (Own/Other's movement smoothness) repeated-measures ANOVA after performing Fisher-z transforms. The backtransformed average correlations are shown in Table 2. The results indicated a main effect for Actor Role, such that deciders showed stronger correlations between movement smoothness and JoC than followers did, $F(1, 74) = 4.52$, $p < .05$, $\eta^2 = .06$. There were no other significant effects for JoC. This finding suggests that JoC ratings were consistent with we-mode processing in general, but that perception–action links were weakened for followers compared to deciders. This was particularly the case when prior intentions were met for the followers, although the interaction between Actor Role and Congruency did not reach significance.

The analysis on movement smoothness and JoPerf (see Table 1) indicated significant correlations for all conditions, but a similar 2 × 2 × 2 ANOVA as reported above did not indicate significant differences across conditions.

3.2. Joint Intention and Intention Negotiation Scenario

As the actor roles emerged dynamically for the joint intention and intention negotiation scenario, I combined these trials for data analysis purposes. I first conducted a mixed model analysis to determine how actor roles influenced JoC and JoPerf. Actor Role was added as a fixed factor and Task Completion Times as a random factor.

Fig. 4 (left panel) shows the JoC results. The analysis on JoC indicated a significant effect of Actor Role, $F(2, 92.97) = 20.60$, $p < .01$. Planned comparisons indicated that JoC was lower in the nondominant trials compared to the joint intention trials ($b = 1.49$, $SE = 0.25$, $t = 5.87$) and the dominant trials ($b = 1.65$, $SE = 0.26$, $t = 6.40$). The joint intention and dominant trials did not differ significantly, $p > .10$.

The analysis on JoPerf (Fig. 4, right panel) showed a similar effect of Actor Role, $F(2, 92.97) = 11.92$, $p < .01$, such that JoPerf was lower for nondominant trials compared to jointintention trials ($b = 0.99$, $SE = 0.20$, $t = 4.85$) and dominant trials ($b = 0.76$, $SE = 0.22$, $t = 3.46$). Thus, when people are dominated, both their JoC and their JoPerf strongly declined. This result is consistent with the notion that being dominated in a joint action may break the we-mode.

Correlational analyses between JoC, JoPerf, and task completion times suggested (and t-tests confirmed) that the correlations between each of the variables differed from zero for each actor's role. In each case, JoC and JoPerf increased as task completion times decreases, and JoC increased with an increase in JoPerf. Repeated-

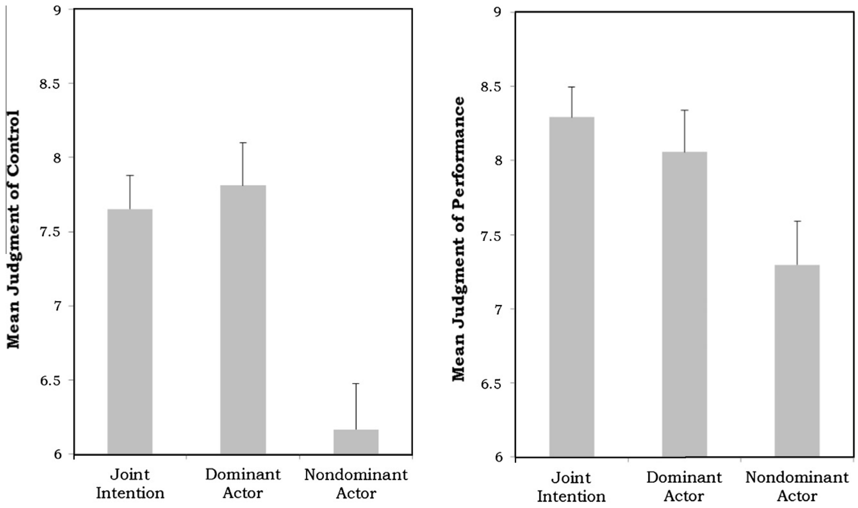

Fig. 4. Mean judgments of control (left panel) and mean judgments of performance ratings (right panel) with standard error bars for the Joint Intention–Intention Negotiation scenario.

measures analyses of the Fisher-transformed correlations (see Table 3) for each pairing of the correlated variables did not indicate differences between Actor Roles, $p > .10$.

I again calculated correlations between movement smoothness, JoC, and JoPerf. These correlations were computed for each actor role, and both for an actor's own movement smoothness as well as for their co-actor's movement smoothness. Table 4 shows the results. T-tests indicated significant correlations between movement smoothness and JoC for all conditions (all $ps < .05$), except between JoC and movement smoothness of the co-actor in the nondominant condition. A 3 (Actor Role) × 2 (Own/Other's Movement smoothness) repeated-measures ANOVA on the Fisher-transformed correlations confirmed this finding by showing a significant interaction, $F(1.65,80.69) = 3.47$, $p < .05$, $\eta^2 = .07$. Thus, participants stopped to pay attention to their co-actor's movements to derive a sense of control when they were dominated. This finding is consistent with I-mode processing.

For JoPerf, all correlations were significantly different from zero, and a 3 (Actor's role) × 2 (Own/Other's Movement smoothness) repeated-measures ANOVA did not indicate differences across conditions.

Table 3
Pearson correlations between judgments of control (JoCs), judgments of performance (JoPerfs), and task completion times (TCTs) for the Joint Intention–Intention Negotiation scenario.

	Pearson correlation *r* (SE)		
	JoCs/JoPerfs	JoCs/TCTs	JoPerfs/TCTs
Joint intention	0.78(0.34)	−0.26(0.08)	−0.52(0.10)
Dominant	0.61(0.34)	−0.22(0.11)	−0.49(0.11)
Nondominant	0.65(0.21)	−0.27(0.05)	−0.45(0.06)

Table 4
Pearson correlations between judgments of control (JoCs), judgments of performance (JoPerfs) and movement smoothness for the Joint Intention–Intention Negotiation scenario.

	Pearson correlation *r* (SE)			
	JoCs/movement smoothness		JoPerfs/movement smoothness	
	Own moves	Partner moves	Own moves	Partner moves
Joint intention	0.11(0.06)	0.28(0.11)	0.19(0.06)	0.41(0.09)
Dominant	0.14(0.07)	0.19(0.09)	0.29(0.08)	0.44(0.10)
Nondominant	0.22(0.09)	−0.08(0.09)[a]	0.31(0.10)	0.40(0.09)

[a] Not significantly different from 0.

3.3. Relative dominance

As pairs differed in the extent to which one actor dominated the other actor, I analyzed whether the JoC and JoPerf correlated with dominance index. This allowed for testing whether having an implicit agreement for one actor to dominate the other may be a strategy that increased the sense of control and perceived performance quality in the nondominant actor. In other words, if one implicitly agrees to be dominated, this may reduce the effect of being dominated on having a lower sense of control. To calculate a dominance index, I divided the number of dominant trials of the actor in the pair who was dominant most often by the total number of intention negotiation trials. Thus, the resulting dominance index ranged from 0.5 (if the actors were equally dominant) to 1 (if one actor always dominated the other actor). Although the correlations for the nondominant actor between dominance index and JoC ($r = .15$), and dominance index and JoPerf ($r = .20$) were both positive, neither reached significance, $p > .10$.

3.4. Comparing across scenarios

There are several comparisons across the presented scenarios that are of further interest for understanding JoC and JoPerf for joint actions. For example, do JoC and

JoPerf when one's prior intention is instantiated still depend on the particular role distribution across actors? To examine this question, I performed a mixed model analysis to compare JoC and JoPerf between the decider congruent, dominant, and joint actor roles. Actor role was a fixed factor and task completion times a random factor here. Fig. 5 shows the result. Whereas the analysis of JoC did not show differences across these actor roles, JoPerf did differ. Interestingly, JoPerf were lower in the dominant role relative to the decider congruent ($b = 0.32$, $SE = 0.15$, $t = 2.14$) and joint actor roles ($b = 0.33$, $SE = 0.14$, $t = 2.36$). Thus, dominating a co-actor reduced the perceived quality of performance for both the dominant and the nondominant actor.

What happens to JoC and JoPerf when prior intentions are not met, and does one's action role matter? To examine this question, I compared the follower incongruent and nondominant actor roles. Fig. 6 shows the results. The mixed model analysis with task completion times as a random factor indicated an effect of Actor role for both JoC ($b = 0.71$, $SE = 0.22$, $t = 3.21$) and JoPerf ($b = 0.43$, $SE = 0.18$, $t = 2.44$). This difference indicates that being dominated degraded both JoC and JoPerf compared to situations in which only a prior intention was not met (i.e., the follower incongruent case).

4. Discussion

The present experiment tested whether participants derived a sense of control based on I-mode processing or we-mode processing when they performed joint parallel actions and took on different roles across trials. The predictions were twofold across the different conditions in the experiment; first, based on I-mode processing, there should be an effect of Actor Role on judgments of control (JoCs). Based on we-mode processing, there should not be such an effect. Second, based on I-mode processing JoCs

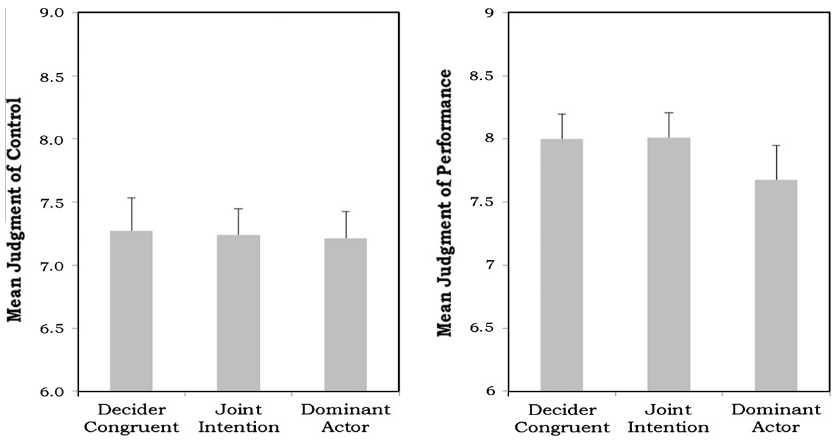

Fig. 5. Role effects for when prior intentions are met. The displayed data show mean judgments of control (left panel) and mean judgments of performance ratings (right panel) with standard error bars.

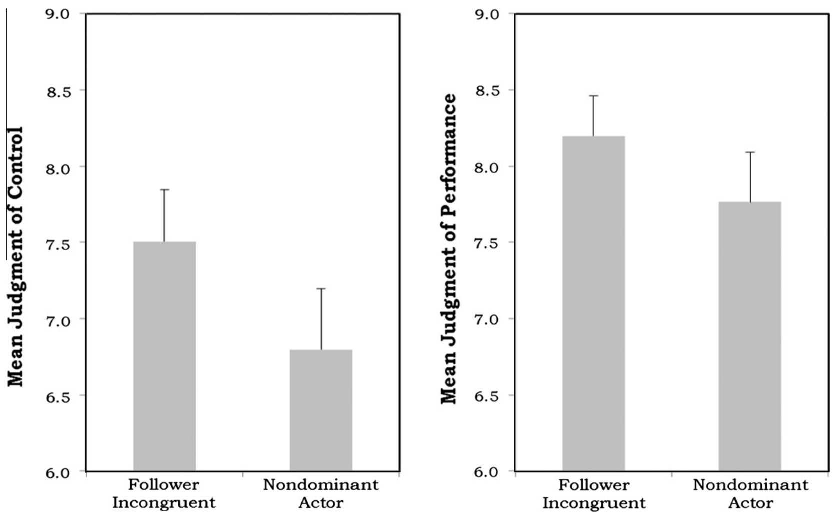

Fig. 6. Role effects for when prior intentions are not met. The displayed data show mean judgments of control (left panel) and mean judgments of performance ratings (right panel) with standard error bars.

should only correlate with a person's own movement parameters, but not with the co-actor's movement parameters (or at least they should correlate much more strongly for one's own versus the co-actor's movements). Based on we-mode processing, correlations between the co-actor's movement parameters and one's own JoCs would be expected. Both of these predictions were tested quantitatively in a decider–follower scenario and in a joint intention–intention negotiation scenario, as well as across scenarios.

The present findings are consistent with the notion that people engaged in we-mode processing during joint parallel actions, and that such processing fed into JoCs and JoPerfs. In particular, unless actors' actions were in direct conflict with one another, actor roles did not systematically influence JoCs and JoPerfs, or the relationships of these variables to objective performance measures. This lack of a difference was particularly informative in cases where the decider and follower had incongruent intentions. In such cases, the visited target was always congruent with the decider's intention (as they controlled the relevant dimension), but it was truly incongruent for the follower's intention. As a result, based on I-mode processing there should have been an effect of Actor Role when comparing the decider "incongruent" ratings with the follower incongruent ratings, but there was not. This is a first indication for we-mode processing instead.

A second indication for we-mode processing stems from the finding that actors showed significant and very similar correlations between JoCs and movement smoothness for their own movements as well as for their partner's movements (in all conditions except when they were dominated). This finding suggests that actors did not derive a sense of control from just their own contributions, as would be expected based on I-mode processing. For the followers, an interesting finding in this regard is that the correlation between both their own and their co-actor's movement smoothness with JoCs was present except when their prior intentions were met. In that case, JoCs for followers seem to have detached from sensorimotor (for own movement smoothness) and perceptual (for the co-actor's movement smoothness) information, and be driven by intention congruency with the decider instead.

For the interpretation of the results, it is important to emphasize that actual differences in performance were statistically accounted for, as task completion times were added as a random factor in the mixed model analyses. When the reported analyses were repeated by adding the number of velocity peaks for each actor as an additional random factor as well, the pattern of results remained the same. Thus, variables related to the actual action effect, such as smoothness of the movements to the target or the durations of the movements, did not account for differences in reported JoCs and JoPerfs.

The finding that actor role did not systematically influence the sense of agency in the decider–follower scenario forms a departure from previous findings by Obhi and Hall (2011a,b). In their studies, followers reported a reduced sense of agency when they pressed a button shortly after their action partner. A difference between those studies and the current study is that here, participants truly produced an action effect together, as they coordinated online rather than sequentially. In the Obhi and Hall studies, it was the case that when the action partner acted, this implied that the co-actor needed to follow. Thus, perhaps the decider–follower scenario in the Obhi and Hall studies was more similar to being dominated in the current study than it was to the decider–follower scenario presented here. How temporal and dynamical aspects of actor roles influence the experience of joint action warrants further studies, however.

Importantly, the current results also suggest that we-mode processing breaks down when actor's actions are in direct conflict with each other with respect to the overarching goal. In such cases, JoCs and JoPerfs strongly degraded when participants were dominated. The decline in both of these measures surpassed the decline in the follower incongruent case. Indeed, the beta coefficients indicate that being dominated resulted in a reduction in JoCs that was actually larger than the observed congruency effect (a beta coefficient of 0.71 for being dominated versus a beta coefficient of 0.57 for congruency). A similar effect of being dominated was observed for performance evaluation (a beta coefficient of 0.43 versus 0.32). These findings indicate that when one's prior intention is not instantiated, it poses a much greater cost on the sense of control and performance evaluation when this happens after an intention negotiation phase than when it is due to a priori role distributions.

The results from the dominant actor also suggest breakdown in we-mode processing. In particular, although being dominant did not impose a cost on JoCs, it did negatively influence JoPerfs in comparison to collaborative trials (i.e., the joint intention and decider congruent conditions). Thus, imposing one's intention may not have compromised the sense of control, but it nonetheless seemed to hurt performance evaluation. Such reduced performance evaluation is important for applied settings, as it may imply lowered performance satisfaction, which in turn may lower one's willingness to continue a joint action (Caruso et al., 2006). Thus, when people engage in a task together for which an asymmetric role distribution may arise (or is thought to be beneficial), it is better if actor roles are established beforehand.

Overall, JoPerfs linked strongly to JoCs. This observation was born out by substantial correlations between these variables across scenarios, actor roles, and conditions. It is important to note here, however, that the correlations between JoCs and task completion times were lower than between JoPerfs and task completion times for all conditions. The beta coefficients for the congruency effect in the decider–follower scenario, and the actor role effect in the joint intention–intention negotiation scenario were consistently larger for JoCs than they were for JoPerfs. This suggests that judgments of control do not just track judgments of performance completely.

The current results strengthen the conclusion drawn by Dewey et al. (2014) that joint actions may rely on we-mode processing when the actors' contributions have perceptually distinguishable consequences. Such we-mode processing may form the default mode of processing for both turn-taking and parallel joint actions. Nonetheless, it is clear that boundary conditions exists to we-mode processing for the sense of control over joint actions, as conflicting performance with respect to the joint goal appears to shift processing from a we-mode to an I-mode, even when such conflict is quickly resolved online.

The finding that congruency between the prior intentions and actual action influenced the JoCs is consistent with previous literature on the sense of agency in individual contexts (e.g., Metcalfe & Greene, 2007). The observation that such an effect occurred after the analyses corrected for objective performance differences suggests that people may be hypersensitive to performance changes in their judgments of control. Cast differently, participants' JoCs and JoPerfs did not veridically reflect the ability to control action outcomes or their quality. The lack of an effect of Actor Role further substantiates this interpretation.

The general congruency effect in the decider–follower scenario fits with the predictive account for the sense of agency, but falls short in some ways as well. Based on the predictive account, the sense of agency should depend on the expected and actual sensory consequences of an action. In particular, the better the incoming sensory information matches the efference copy containing the sensorimotor signals used to produce the movements, the stronger the reported sense of agency should be. Both the congruency effect and the correlations between movement smoothness and an actor's own JoCs are consistent with this predictive account. On the other hand, the sensorimotor account does not predict correlations between a co-actor's movements and one's own sense of control, as sensorimotor prediction is not available for these movements. Thus, the predictive account needs to be augmented to include prediction at the perceptual level for joint actions, and should elaborate on how sensorimotor signals and perceptual information together give rise to a sense of joint control.

Both predictive and postdictive accounts on the sense of agency fall short in fully accounting for the results reported here in other ways as well. For example, neither of these accounts predicts the substantial differences in JoCs between the follower incongruent and nondominant conditions observed here. As consistency was violated in both of these conditions, JoCs should have been reduced to an equal extent. The results indicated a much larger reduction when participants were dominated. The postdictive account additionally falls short with respect to the role of exclusivity. Within that framework, other actors reduce exclusivity, but no account is provided on the extent to which such exclusivity may depend on what role other actors play in an action. In the case of joint actions, one possibility may be to consider exclusivity with respect to the unit of joint actors, rather than with respect to individual agents.

Little is still known about the experiential nature of joint actions (but see Dewey et al., 2014; Pacherie, 2013; van der Wel, Sebanz, & Knoblich, 2012). Such actions form a ubiquitous ingredient of everyday life, and yet provide an inherently ambiguous context for tracking one's own action contributions. This ambiguity provides a puzzle for how people derive a sense of agency over joint actions. The current study informs the development of theories on the experience of joint actions taking place over relatively short time scales. Such theories in turn may inform the qualities of cooperation and team performance in a broad sense.

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