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How Two Share a Task: Corepresenting Stimulus–Response Mappings

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Previous research has shown that individuals unintentionally adjust their behavior to others by mimicking others' actions and by synchronizing their actions with others. This study investigated whether individuals form a representation of a coactor's task when the context does not require interpersonal coordination. Pairs of participants performed a reaction time (RT) task alongside each other, responding to 2 different dimensions of the same stimulus. Results showed that each actor's performance was influenced by the other's task. RTs on trials that required a response from both participants were slowed compared with trials that required only a response from 1 actor. Similar results were observed when each participant knew the other's task but could not observe the other's actions. These findings provide evidence that shared task representations are formed in social settings that do not require interpersonal coordination and emerge as a consequence of how a social situation is conceptualized.

Keywords: corepresentation, task sharing, perception–action link, social understanding, joint action

Even seemingly simple social interactions like making space for other passengers on a crowded bus, helping a friend to carry a table, or buying a newspaper from a street vendor require a range of cognitive abilities. In particular, individuals must be able to perceive socially relevant information (e.g., Allison, Puce, & McCarthy, 2000), coordinate their actions with others (Clark, 1996; Knoblich & Jordan, 2003), and infer others' mental states (Frith & Frith, 1999). Otherwise, they would miss another passenger's angry glare, they would fail to lift the table at the same moment in time as their friend, and they would not know that the newspaper vendor wants to sell them a newspaper even though he is talking to a friend and not watching out for customers.

Humans are not only remarkably good at understanding and participating in social interactions but also unintentionally engage in social behavior, performing actions to match others, synchronizing their actions with others in time, and simulating others' mental states, even when their current action goal does not require to take others' actions or intentions into account. We believe that this tendency to unintentionally "tune in" to others may provide a basis for more complex social interactions and deserves to be studied more closely. In the present study, we explore under which conditions individuals acting in a social context form a representation of others' tasks and how such shared task representations affect action planning and control.

Coordination and Corepresentation

The tendency to pick up social information and unintentionally adjust one's behavior to others' manifests itself in two ways. One is *coordination*, and the other is *corepresentation*. *Coordination* takes place when two or more individuals unintentionally adjust the timing of their actions to each other so that their actions become synchronized. Evidence for the unintentional synchronization of actions comes from studies on rhythmic synchrony, showing that interaction partners coordinate their speech and body movements (Condon & Sander, 1974; Dittmann & Llewellyn, 1969; Kendon, 1970; McDowall, 1978), and from studies on the unintentional synchronization of rhythmic movements, such as swinging a handheld pendulum (Richardson, Marsh, & Schmidt, 2005; Schmidt & O'Brian, 1997). Following the work of Schmidt and colleagues, it seems that a promising way to understand unintentional synchronization is provided by dynamical systems theory, which conceptualizes this phenomenon as a self-organized entrainment process of a coupled-oscillator dynamic (cf. Richardson et al., 2005; Schmidt, O'Brian, & Sysko, 1999).

Corepresentation takes place when an individual shares another individual's mental representation. In the following, we consider only the corepresentation of actions and intentions, but it is likely that other representational contents (e.g., feelings or beliefs) can unintentionally come to be shared as well. The terms *corepresentation* and *shared representation* are used synonymously throughout the text. How does an individual come to share another's representation of a goal-directed action? An answer to this question is provided by ideomotor theory (Greenwald, 1970, 1972; James, 1890). According to an extended form of the ideomotor principle, observing an action leads to corepresentation, because observing or imagining a certain event in the environment activates the representational structures involved in the planning and execution of the action that has been learned to produce this event

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(Greenwald, 1970; Jeannerod, 1999; Prinz, 1997). Therefore, observing somebody perform an action should also activate corresponding motor representations in the observer and create an action tendency. A range of findings supports this claim.

First, studies on nonconscious mimicry have shown that in many social situations, individuals unintentionally adopt the postures (Bernieri & Rosenthal, 1991; Chartrand & Bargh, 1999; La France, 1979, 1982; La France & Broadbent, 1976), mannerisms (Chartrand & Bargh, 1999), and facial expressions (e.g., Anisfield, 1979; Bavelas, 1986) of an interaction partner. These findings can be explained by the assumption that observing an action creates a tendency in the observer to perform the same action, because observed and planned actions share common representational structures (see Chartrand & Bargh, 1999).

Second, the notion that common representational structures are involved in action observation and planning has received support from behavioral studies demonstrating that performance of an action is facilitated when it is identical with a concurrently observed action and impaired when the observed action and the action to be performed do not correspond (cf. Brass, Bekkering, & Prinz, 2001; Kilner, Paulignan, & Blakemore, 2003; Stürmer, Aschersleben, & Prinz, 2000). For example, performing a grasping movement takes less time when one observes a hand performing a grasping movement than when one observes a hand performing a spreading movement (Stürmer et al., 2000).

Finally, evidence for the corepresentation of observed actions is also provided by brain imaging and neurophysiological studies. Mirror neurons in the ventral premotor cortex and the parietal cortex of the macaque monkey have been shown to discharge both when a monkey performs an action and when it observes another individual performing the same action (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti & Craighero, 2004; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; Rizzolatti, Fogassi, & Gallese, 2001). Thus, they provide a neural mechanism for the direct mapping of observed actions onto motor representations. Studies using functional magnetic resonance imaging (fMRI) and positron emission tomography have provided evidence that a mirror system also exists in humans. Several brain areas are activated during both observation and execution of an action (Blakemore & Decety, 2001; Buccino, Binkofski, & Riggio, 2004; Grèzes & Decety, 2001; Grèzes, Passingham, & Frith, 2004).

Corepresentation in the Absence of Action Perception

All of the studies described above suggest that for representational structures that guide one's own planning and performance of a particular action to be activated, at least some part of somebody else's action, if not the whole action (see Umiltà et al., 2001), must be perceived. Are there alternative mechanisms that can give rise to shared action representations? For instance, are the potential actions of others represented when they are not concurrently observed, as when two individuals take turns in performing two different actions?

To address this question, in an earlier study we investigated whether a cue referring to the potential action of another individual creates an action conflict for the current actor (Sebanz, Knoblich, & Prinz, 2003; Sebanz, Knoblich, Stumpf, & Prinz, 2005). This would indicate that the other's action is corepresented even when the other is never acting at the same time. A two-choice reaction time (RT) task was distributed among two people sitting alongside each other. One person responded to one color, and the other person responded to the other color (see Figure 1b). Thus, each of the 2 participants in the group performed a go/no-go task (e.g., responding to red and not to green). In addition, the stimuli contained an irrelevant spatial cue, pointing either at the person in charge of the left response[1] or at the person in charge of the right response.

Previous research has shown that when a stimulus and an action share a spatial feature, the stimulus automatically activates the action through a direct link (stimulus–response compatibility; Kornblum, Hasbroucq, & Osman, 1990; Proctor & Reeve, 1990). For example, when the finger points left, the left response will be activated. Accordingly, we predicted that if coactors represent each other's actions, an irrelevant spatial cue referring to the other's action should activate the representation of the other's action and create a response conflict. As predicted, RTs were slowed on trials in which the spatial cue did not point at the person who was to respond but at the other person. This slowing was not observed when each participant performed the same task alone (see Figure 1a) or when the other participant was present but did not act. Thus, the irrelevant spatial cue selectively caused interference when it referred to another's potential action, suggesting that corepresentation does not necessarily depend on action perception.

This conclusion was further supported by a follow-up experiment, in which the same pattern of results was obtained in a group setting wherein participants could not observe each other's actions at all. Corepresentation may thus emerge not only as a consequence of observing actual actions but also as a result of knowing about potential actions of others. This, in turn, raises the possibility that not others' actions per se are represented but rather the task rules that govern a coactor's actions.

Corepresentation of Tasks?

In the present study, we investigated this possibility by asking whether individuals working on different tasks alongside each other form a representation of each other's task. We used the following standard definition of *task* (cf. Monsell, 2003; Rubinstein, Meyer, & Evans, 2001): a rule or a set of rules specifying the stimulus conditions under which one or more actions are to be performed. Sharing a task representation or corepresenting a task then means that an individual represents at least one rule that states the stimulus conditions under which a coactor should perform a certain action.

What is the difference between corepresenting a task and corepresenting an action? Corepresenting an action implies only knowledge about features of an action a particular person is performing, but no knowledge about the specific stimulus conditions that evoke the action. In contrast, corepresenting a task implies knowledge about a specific relationship between particular stimulus conditions and particular actions (see Figure 2).

Accordingly, different mechanisms mediate the activation of a representation of another's action or task through particular stim-

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[1] Following the standard terminology of experimental psychology, we use the term *response* to refer to actions that are performed contingent on particular stimulus features.

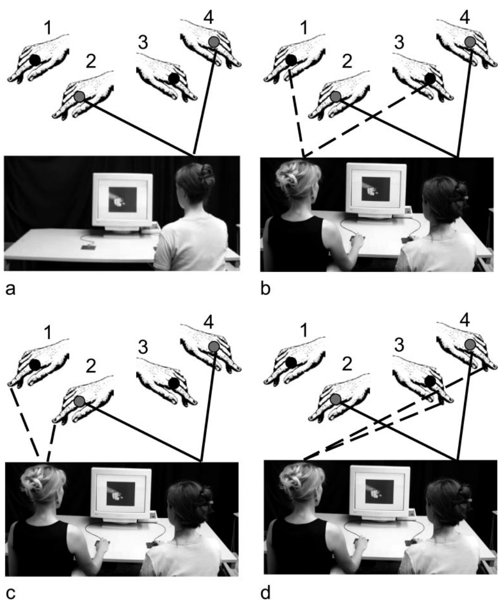


Figure 1. Illustration of the experimental conditions. Simplified depictions of the stimuli are shown above the setting (the stimuli are numbered 1–4). On each trial, only one stimulus was presented at a time. The black lines show which stimuli are go trials for the right person, and the dotted lines show which stimuli are go trials for the left person. In the examples illustrated here, the person sitting to the right has received the instruction to respond to green stimuli (2 and 4). The person sitting to the left is absent in the individual condition (Panel a). In the remaining conditions, the person sitting to the left receives the instruction to respond to red stimuli (1 and 3 in Panel b: Group Condition III), to respond whenever the finger points toward her (1 and 2 in Panel c: Group Condition I; compatible direction task), and to respond whenever the finger points away from her (3 and 4 in Panel d: Group Condition II; incompatible direction task). In the individual condition and Group Condition III, each stimulus requires a response from 1 participant (Panels a and b). In Group Conditions I and II, some stimuli require a response from 1 participant (single-response trials), some require a response from both participants (double-response trials), and some do not require a response (Panels c and d).

uli. When an action is corepresented, a stimulus sharing a feature with the corepresented action will activate the corepresented action through a direct link. For example, when a stimulus points left, a representation of a left action will automatically be activated because of the overlap between stimulus and action features (see, e.g., Hommel & Prinz, 1996; Kornblum et al., 1990).

When a task is corepresented, arbitrary stimuli for which a corepresented task rule specifies a certain action will activate this task rule. For example, when one knows that the other's task is to respond to green, seeing a green stimulus will activate the respective rule. Thus, in the case of task corepresentation, a direct overlap between stimulus and action features is not required. However, the activation of a corepresented task rule can create a conflict when one needs to act according to a different task rule at the same time. For example, when one's own task is to respond to stimuli pointing to the right, seeing a green stimulus pointing to the right will cause a conflict between the task rule that governs one's own actions ("respond to right") and the corepresented task rule ("respond to green"). Note that action corepresentation and task corepresentation can occur at the same time. The same stimulus can activate a corepresented task rule and also activate a corepresented action through a direct stimulus–action link.

We conducted two experiments to determine whether coactors represent each other's task and to assess relative effects of action and task corepresentation. Participants responded to stimuli that varied on two dimensions (color and pointing direction; see Figure 1c and Figure 1d). One coactor's task was to respond to a specific color (color task; e.g., respond to green and not to red) and the other coactor's task was to respond to a specific pointing direction (direction task; e.g., respond to left and not to right; see Figure 1c). The aim of Experiment 1 was to examine whether performance of the direction task is influenced by the color task, and vice versa, when participants act alongside each other. In Experiment 2, we investigated whether coactors performing these different tasks also influence each other's performance when they do not receive feedback about each other's actions but know each other's tasks.

Experiment 1

We used task conflict as an indication of task corepresentation. The way the color and the direction task are distributed among pairs of participants implies that some stimuli require a response from only one of the two actors (see Stimulus 1 and 4 in Figure 1c,

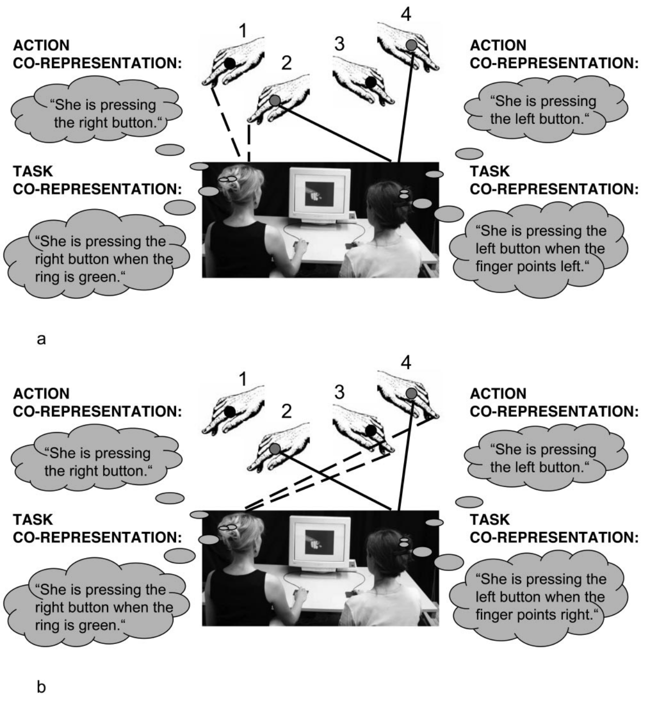


Figure 2. Illustration of action and task corepresentation. The think bubbles illustrate the difference between corepresentation of action and corepresentation of task. The upper panel shows Group Condition I (right participant responds to green, left participant responds to compatible direction), and the lower panel shows Group Condition II (right participant responds to green, left participant responds to incompatible direction). As can be seen from the illustration, if the other's task is represented, then the other's action should be represented as being contingent on a particular stimulus.

and Stimulus 2 and 3 in Figure 1d), whereas a particular stimulus requires a response from both actors (see Stimulus 2 in Figure 1c and Stimulus 4 in Figure 1d). If coactors represent each other's task, then a conflict should arise when a stimulus appears that requires each coactor to apply a different task rule. We predicted that this conflict between two task rules would impair performance on such *double-response trial*s, in which a stimulus required a response from both participants, compared with trials in which only one response was required.

However, it is also possible that coactors only form a representation of each other's action alternative. In this case, a corepresented action should be activated when a stimulus refers to the other's action through a direct link (feature overlap). If such a stimulus requires one's own action, the activation of the corepresented action should create an action conflict. This conflict should manifest itself in impaired performance. In Experiment 1 we determined the relative effects of task corepresentation and action corepresentation.

Pure Task Representation Effects

Effects of task corepresentation alone can be measured by analyzing performance of the direction task. Half of the participants performing the direction task responded to stimuli pointing toward themselves, alongside a coactor performing the color task (see Figure 1c). The other half of participants performing the direction task responded to stimuli pointing away from themselves alongside a coactor performing the color task (see Figure 1d). In both conditions, we compared RTs and errors on double-response trials, in which a color response from the other participant was also required, with single-response trials. Our prediction was that performance on double-response trials would be impaired.

As shown in Figure 3A, comparing double and single-response trials in these conditions allows one to measure effects of pure task conflict and, thus, task corepresentation. Action conflict, induced by a direct link between the stimulus and the other's response, is not reflected in the comparison between double and single-response trials. In Group Condition I, in which participants responded to compatible direction, there is no action conflict (see Figure 3A; compare *Double response* and *Direction response*). In Group Condition II, in which participants responded to incompatible direction stimuli, there is the same action conflict both on double and single-response trials (see Figure 3B; compare *Double response* and *Direction response*).

Comparing Effects of Task Corepresentation and Action Corepresentation

The relative effects of task corepresentation and action corepresentation can be measured by analyzing performance of the color task. Half of the participants performed the color task alongside a coactor performing the compatible direction task (Group Condition I; see Figure 1c). The other half of participants performed the color task alongside a coactor performing the incompatible direction task (Group Condition II; see Figure 1d). In both conditions, we compared RTs and errors in the color task on double-response trials, in which a direction response from the other participant was also required, with single-response trials.

By analyzing performance in Group Condition II (other responds to incompatible direction), one can assess whether the effects of task conflict or action conflict are more pronounced. On double-response trials, participants in charge of the color task should encounter a task conflict but no action conflict. However, on single-response trials, they should encounter an action conflict but no task conflict (see Figure 3B; compare *Double response* and *Color response*). The action conflict arises because the irrelevant pointing stimulus refers to the other's action and should activate the corepresented action via a direct link. If performance on double-response trials is worse than performance on single-response trials, the effects of task conflict are more pronounced than the effects of action conflict. If performance on single-response trials is worse than performance on double-response trials, the effects of action conflict are more pronounced than the effects of task conflict.

By analyzing performance of the color task in Group Condition I (other responds to compatible direction), one can assess the combined effects of task corepresentation and action corepresentation. As can be seen in Figure 3A (compare *Double response* and *Color response*), participants in charge of the color task should encounter a task conflict and an action conflict on double-response trials but encounter neither of these on single-response trials. Thus, on double-response trials, the effects of task and action conflict should add up. To single out the effects of task conflict, one needs a condition for comparison, in which only an action conflict but no task conflict is present. For this purpose, we included Group Condition III, in which each of two participants responded to one color (see Figure 1b). In this condition there is no task conflict because each stimulus activates only one task rule. However, there is action conflict when the irrelevant pointing direction of the stimulus refers to a corepresented action (see Figure 3C). To the extent to which the performance drop on conflict trials is more pronounced in Group Condition I than in Group Condition III, task conflict occurs in addition to action conflict.

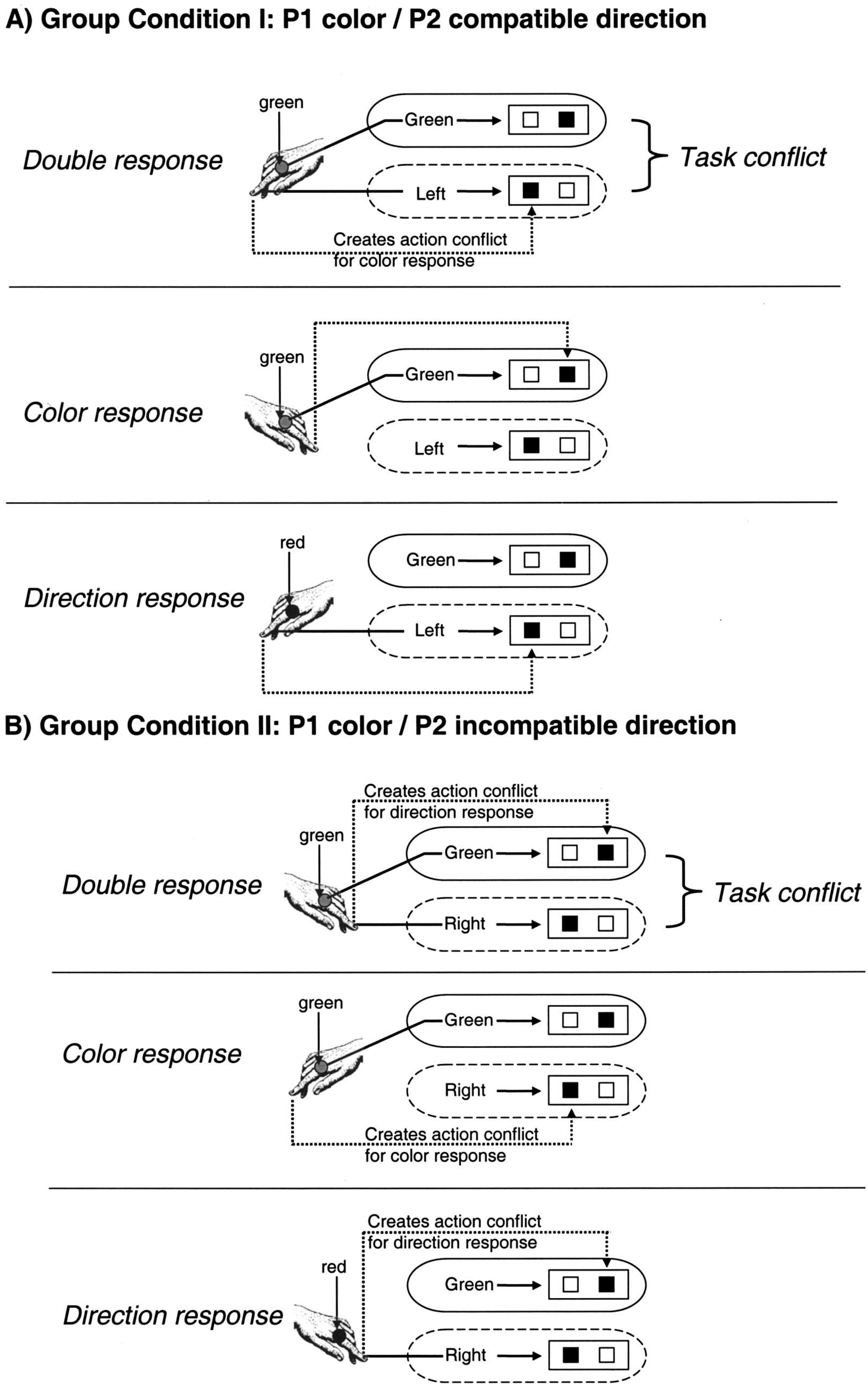
Pure Action Representation Effects

Finally, to replicate the earlier effects of action corepresentation proper (Sebanz et al., 2003; Sebanz, Knoblich, Stumpf, & Prinz, 2005), we also included an individual color condition. Participants performed the color task alone (responding to one color and not the other; see Figure 1a). In this condition the irrelevant pointing stimulus should not affect performance, because there is no action to corepresent (see Figure 3D). By comparing performance in Group Condition III (each participant responds to one color) with performance in the individual color condition one can assess the effects of action corepresentation alone.

Method

Participants. Thirty-two paid participants (7 men and 25 women) between the ages of 19 and 32 years took part in the experiment. They were recruited by advertisements at the University of Munich, Munich, Germany, and in local newspapers. All were right handed and had normal or corrected-to-normal vision.

Materials and apparatus. Participants responded to digital photographs of a right human hand pointing to the left or to the right. On the index finger there was a ring colored red or green. The stimuli were presented centrally, and the ring always appeared at the same location.


A) Group Condition I: P1 color / P2 compatible direction
Double response
green
Green
Left
Task conflict
Creates action conflict for color response
Color response
green
Green
Left
Direction response
red
Green
Left
B) Group Condition II: P1 color / P2 incompatible direction
Creates action conflict for direction response
Double response
green
Green
Right
Task conflict
Color response
green
Green
Right
Creates action conflict for color response
Creates action conflict for direction response
Direction response
red
Green
Right

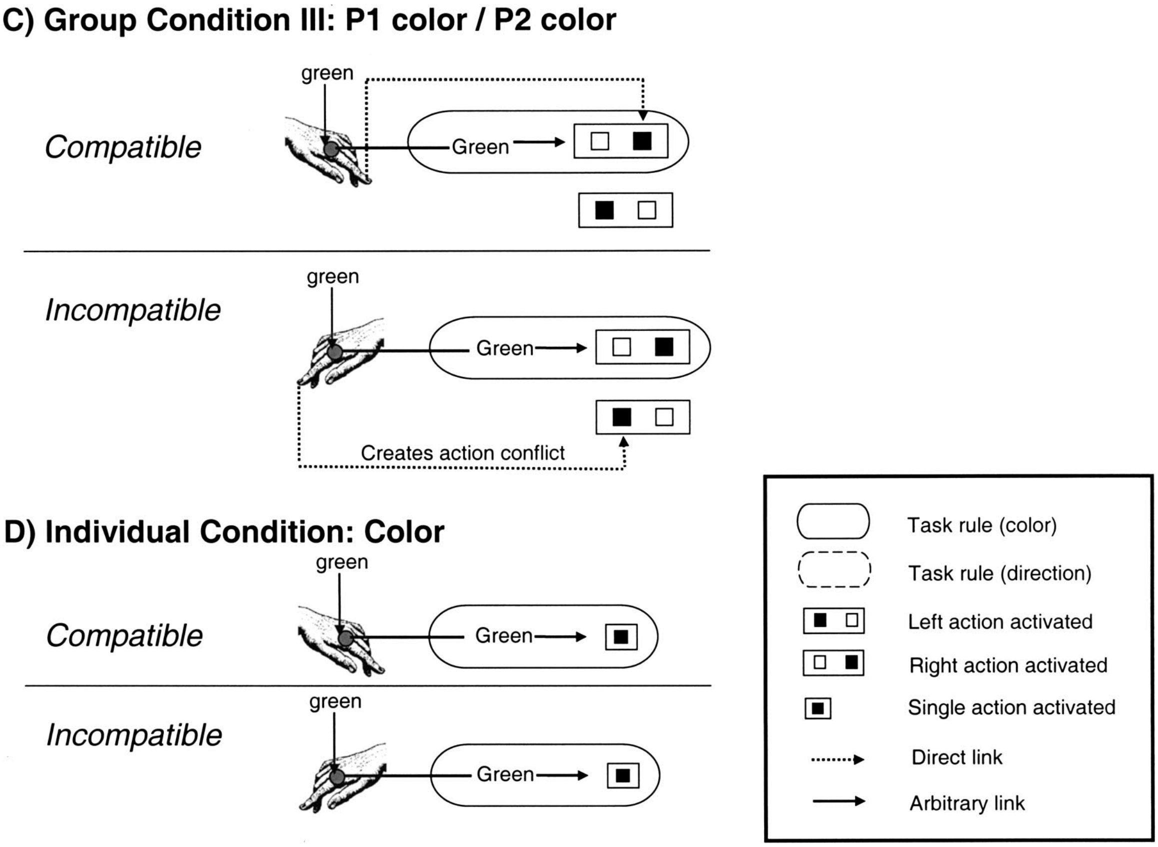


Figure 3. Illustration of the predictions for action and/or task conflict on go trials in each condition. In the example illustrated here, the right person (P1) responds to green. The left person (P2) responds to compatible direction (A; Group Condition I), to incompatible direction (B; Group Condition II), to red (C; Group Condition III; the illustrations show only go trials for the right person), or is absent (D; individual condition). A and B: Task conflict on double response trials. C: Action conflict on incompatible trials. D: No conflict.

Picture size was 15 × 13 visual degree horizontally and vertically. Stimulus presentation and data collection were controlled by an Apple Power PC. The pictures were presented on an Apple 21-in. monitor (resolution 1024 × 768 pixels). Button presses were recorded with a PsyScope button box (Cohen, MacWhinney, Flatt, & Provost, 1993).

Procedure. Two different tasks were performed. One task was a go/no-go task in response to color (color task). Participants responded to one color (e.g., green) by pressing a button and not to the other color (e.g., red). The other task was a go/no-go task in response to pointing direction (direction task). Participants performing this task responded to one pointing direction (e.g., left) and not to the other direction (e.g., right). They responded either to stimuli pointing at themselves (compatible direction) or to stimuli pointing away from themselves (incompatible direction).

In Group Condition I, 1 participant performed the compatible direction task alongside a person performing the color task (see Figure 1c); in Group Condition II, 1 participant performed the incompatible direction task alongside a person performing the color task (see Figure 1d); in Group Condition III, each of 2 participants performed the color task (i.e., 1 participant responded to red, and the other to green; see Figure 1b); and in the individual condition, participants performed the color task alone (see Figure 1a).

The instructions for the task were always displayed on the computer monitor before the start of the experiment. In the individual condition the instruction stated the task for one person (e.g., "Your task is to press the button in front of you whenever the stimulus is red"). The instruction in the group conditions stated the task for each participant (e.g., "The person sitting left has the task to respond to red stimuli by pressing the button in front of him/her, and the person sitting right has the task to respond to stimuli pointing at him/her by pressing the button in front of him/her"). The sequence of events on each trial was as follows: A black fixation cross appeared on the screen for 100 ms, followed after 100 ms by a picture of the hand, which remained on the screen for 500 ms. From the onset of the picture, participants had 600 ms to give a response. The next trial was initiated 1,000 ms after picture onset. In each condition, participants completed four blocks of 100 trials. Each of the stimuli appeared an equal number of times within each block, and the order of stimulus presentation was random.

Design. Participants were assigned to one of four groups of equal size. Participants in each group performed three different conditions (see Table 1; Groups A, B, C, and D). The order in which the conditions were run was counterbalanced across pairs of participants.

Results

The results were analyzed in three steps. First, we tested for "pure" task corepresentation effects that should be independent of action corepresentation. In a second step, we assessed the relative

Table 1
Group Assignment in Experiment 1

Group	Group condition I[a]	Group condition II[b]	Group condition III[c]	Individual condition[d]
A	Color task		Color task	Color task
B		Color task	Color task	Color task
C	Direction task		Color task	Color task
D		Direction task	Color task	Color task

[a] One participant responds to one color, and the other responds to compatible pointing direction. [b] One participant responds to one color, and the other responds to incompatible pointing direction. [c] Both participants respond to one color. [d] One participant responds to one color.

effects of task and action corepresentation. Finally, we analyzed effects of action corepresentation alone. Both RTs for correct responses and error rates were analyzed. Two types of errors can occur in the go/no-go tasks to direction and color: false alarms (responding when it is not one's turn) and omissions (failing to respond when it is one's turn). Given that the critical comparisons are between double and single-response trials, the only type of error that can be analyzed for the present purposes are omissions. False alarms per definition cannot occur on double-response trials, in which a response from each participant is required. Omissions were defined as trials in which a participant did not respond within the given time limit of 600 ms.

Pure task representation effects. To test for task representation effects, we analyzed performance of the direction task. The RTs were entered into a 2 × 2 analysis of variance (ANOVA), with direction task (compatible vs. incompatible) as the between-subjects variable and response type (single vs. double response) as the within-subjects variable. The main effect for direction task was not significant, $F(1, 14) = 0.366$, $p = .56$. There was a significant main effect for response type, $F(1, 14) = 9.262$, $p < .01$. As predicted, RTs were slower on double-response trials (see Figure 4A). The Direction Task × Response Type interaction was not significant, $F(1, 14) = 2.583$, $p = .13$. However, two-sided t tests showed that the RT difference between single and double-response trials was only significant in the incompatible direction condition, $t(7) = 3.10$, $p < .05$, but not in the compatible direction condition, $t(7) = 1.09$, $p = .31$.

The same analyses were performed to test for significant differences in omissions. Overall, omissions occurred on 3.6% of all trials ($n = 16$). The analyses did not reveal any significant differences (all $ps > .10$).

Comparing effects of task corepresentation and action corepresentation. To determine whether the effects of task conflict or action conflict were more pronounced, we analyzed responses to color in Group Condition II (other responds to incompatible direction). Numerically, RTs on double-response trials were slower than RTs on single-response trials (see Figure 4B), suggesting that task effects might indeed be more pronounced than action effects. However, a two-sided t test did not reveal a significant difference between RTs on single and double-response trials, $t(7) = 1.47$, $p = .18$.

To assess the combined effects of task corepresentation and action corepresentation, we analyzed performance of the color task in Group Condition I (other responds to compatible direction). A two-sided t test showed that RTs on double-response trials were significantly slower than RTs on single-response trials, $t(7) = 5.70$, $p < .001$, indicating that conflict occurred on double-response trials. To single out the relative effect of task conflict, we compared performance of the color task in Group Condition I (other responds to compatible direction) and Group Condition III (other responds to other color). Remember that to the extent to which the performance drop is more pronounced in Group Condition I (see the left set of double vs. single bars in Figure 4B) than in Group Condition III (see the left set of incompatible vs. compatible bars in Figure 4C), task conflict occurs in addition to action conflict. A 2 × 2 within-subjects ANOVA, with group condition (I vs. III) and conflict (present vs. absent) as variables, was conducted on the RTs. The main effect for group condition was not significant, $F(1, 7) = 1.422$, $p = .272$. The main effect for conflict, $F(1, 7) = 26.097$, $p < .01$, and the Group Condition × Conflict interaction, $F(1, 7) = 27.088$, $p < .01$, were highly significant. This suggests that in Group Condition I, task conflict was present in addition to action conflict.

The overall rate of omissions was 2.6% ($n = 16$). All analyses that were performed on the RTs were also performed on the omissions. There were no significant effects (all $ps > .10$).

Pure action corepresentation effects. Finally, to assess effects of action corepresentation alone, we compared performance in Group Condition III (other responds to other color) with performance in the individual color condition. The RTs were entered into a 2 × 2 within-subjects ANOVA, with condition (Group Condition III vs. individual condition) and compatibility (compatible vs. incompatible) as variables. The main effect for condition was not significant, $F(1, 31) = 0.702$, $p = .409$. There was a significant main effect for compatibility, $F(1, 31) = 43.371$, $p < .001$. RTs were faster on compatible than on incompatible trials. As predicted, there was a significant Condition × Compatibility interaction, $F(1, 31) = 7.465$, $p < .05$, indicating that the compatibility effect was more pronounced in the group setting.

Omissions were 1.3% in the group-compatible condition, 2.9% in the group-incompatible condition, 0.6% in the individual-compatible condition, and 0.7% in the individual-incompatible condition. The same ANOVA as for RTs was performed for omissions. It revealed a significant main effect for condition, $F(1, 31) = 26.155$, $p < .001$. More omissions occurred in the group condition. There was also a significant main effect for compatibility, $F(1, 31) = 20.341$, $p < .001$. The Condition × Compatibility interaction was significant, $F(1, 31) = 11.396$, $p < .01$. There were less omissions on compatible trials than on incompatible trials in the group, whereas there was no difference in the individual condition. The results for RTs and omissions both support the claim that the other's action was corepresented.

Discussion

The analysis of the direction task provided evidence for task corepresentation. As predicted, a slowing of RTs on double-response trials was observed. This suggests that a stimulus requiring a response from both participants created a task conflict, because two task rules were activated at the same time. Further evidence for task corepresentation was obtained by analyzing performance of the color task. The comparison between Group Condition I (task conflict and action conflict) and Group Condition

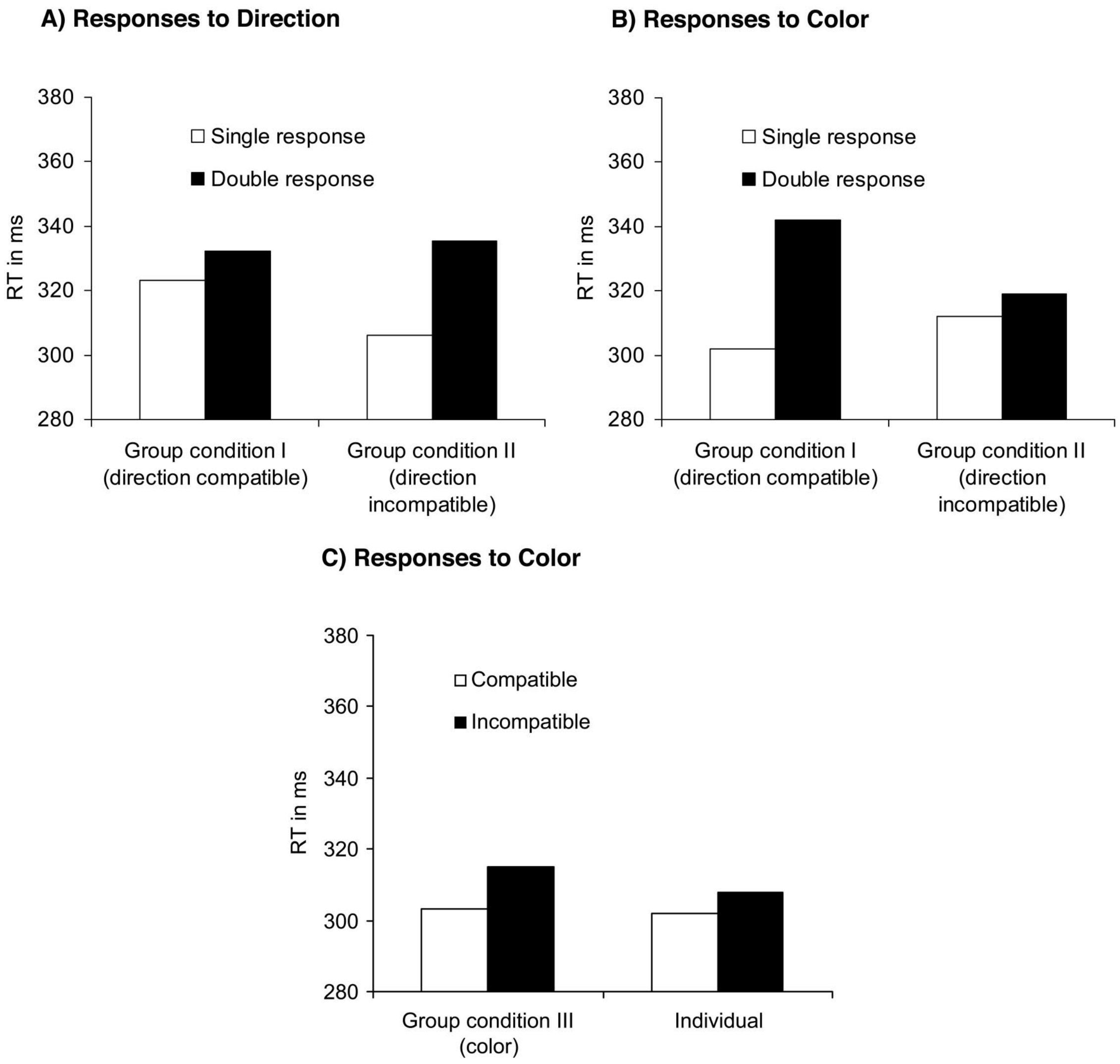


Figure 4. Results from Experiment 1. A: Responses to direction for single-response and double-response trials. B: Responses to color for single-response and double-response trials. C: Responses to color for compatible and incompatible trials. RT = reaction time.

III (action conflict only) showed that the slowing of RTs on double-response trials in Group Condition I was not exclusively due to action conflict. More likely, it reflects combined task conflict and action conflict. Note that the RT difference between double-response trials and single-response trials was more pronounced in this condition than in all other conditions.

In addition, there was clear evidence for action corepresentation in the absence of task corepresentation. We replicated previous results showing that the irrelevant pointing stimulus creates action conflict by activating a corepresented action through a direct link. Contrary to previous findings, there was a small but significant compatibility effect in the individual condition. We cannot be sure how this effect emerged. It may be due to carryover effects from group conditions performed prior to this condition, or it could be a kind of compatibility effect in its own right (see Hommel, 1996). Further investigation of this effect is warranted but is beyond the scope of the present study.

Are effects of action corepresentation or effects of task corepresentation more pronounced? The analysis of color responses in Group Condition II, in which we compared double-response trials (task conflict present) with single-response trials (action conflict present), did not provide a clear answer. Numerically, RTs on double-response trials were slower than RTs on single-response trials, suggesting that effects of task corepresentation prevailed. However, this effect did not reach statistical significance. This might be due to the small number of participants in each group ($n = 8$).

Another predicted effect that remains uncertain is the lack of a difference between double-response trials and single-response trials in the direction task in Group Condition I. Although a slowing of RTs on double-response trials was numerically present, the effect was not statistically significant. Again, the small sample size entering the comparison could be responsible ($n = 8$). In Experiment 2, a larger number of participants performed the color and the direction task in Group Conditions I and II, allowing us to reassess whether an effect of task corepresentation can also be found for the direction task in Group Condition I, as well as to determine the relative contribution of task corepresentation and action corepresentation effects.

Taken together, the results provide evidence that coactors performing different tasks form shared representations of each other's tasks. Both performance of the color task and performance of the direction task were influenced by the coactor's task. The findings suggest that a task conflict occurs when a stimulus is perceived that requires each coactor to apply a different task rule. We found evidence that action corepresentation and task corepresentation can occur in isolation but can also affect performance simultaneously. Whether effects of action corepresentation or effects of task corepresentation are more pronounced is an open issue for Experiment 2.

Experiment 2

The main aim of Experiment 2 was to investigate further under which conditions tasks are corepresented. Individuals performed two different tasks alongside each other as in Experiment 1 but did not receive visual or auditory feedback about their own and the other's actions. This manipulation allowed us to address the question whether tasks are also corepresented when individuals know about each other's tasks but do not receive corresponding information about each other's actions. If similar effects of task conflict as in Experiment 1 are observed, this would provide evidence that shared task representations can emerge as a consequence of how individuals conceptualize a social situation and do not necessarily depend on action perception. Furthermore, repeating the critical group conditions with more participants allowed us to reassess the predictions for task corepresentation that remained uncertain in Experiment 1.

Method

Participants. Thirty-two new participants (9 men and 23 women) between the ages of 19 and 31 years took part in the experiment. All were right handed and had normal or corrected-to-normal vision. They received payment for participation.

Materials and apparatus. These were the same as in Experiment 1.

Procedure. These were the same as in Experiment 1 with the following exceptions. Participants wore ear plugs and headphones to make button presses inaudible. The hand used for the button press rested in a box and was invisible. Participants performed Group Condition I, Group Condition II, and the individual color condition. The results of the individual color condition are not relevant for the present purpose and are not reported.

Design. Each participant performed the color task alongside a participant performing the direction task, and the direction task alongside the same participant performing the color task. Half of the participants were assigned to Group Condition I (compatible direction task) and half to Group Condition II (incompatible direction task).

Results

Pure task representation effects. To test for task representation effects, we analyzed performance of the direction task. The RTs were entered into a 2 × 2 ANOVA, with direction task (compatible vs. incompatible) as a between-subjects variable and response type (single vs. double response) as a within-subjects variable. Contrary to Experiment 1, there was a significant main effect for direction task, $F(1, 30) = 6.128$, $p < .05$ (see Figure 5). RTs were faster in the compatible direction task. The main effect for response type was significant once more, $F(1, 30) = 148.586$, $p < .001$. This time the Direction Task × Response Type interaction was significant, $F(1, 30) = 6.817$, $p < .05$. The effect was more pronounced in the incompatible direction task. Two-sided t tests showed a significant difference between RTs on single and double-response trials both for the compatible condition, $t(15) = 7.23$, $p < .001$, and for the incompatible condition, $t(15) = 9.88$, $p < .001$.

The overall rate of omissions was 4.3% ($n = 32$). There was a significant difference between the rate of omissions on double (3.2%) and single (5.4%) response trials in Group Condition I (compatible direction), $t(15) = 2.25$, $p < .05$, but not in Group Condition II (incompatible direction; $p > .10$).

Comparing effects of task corepresentation and action corepresentation. Responses to color in Group Condition II (other responds to incompatible direction) were analyzed to assess whether

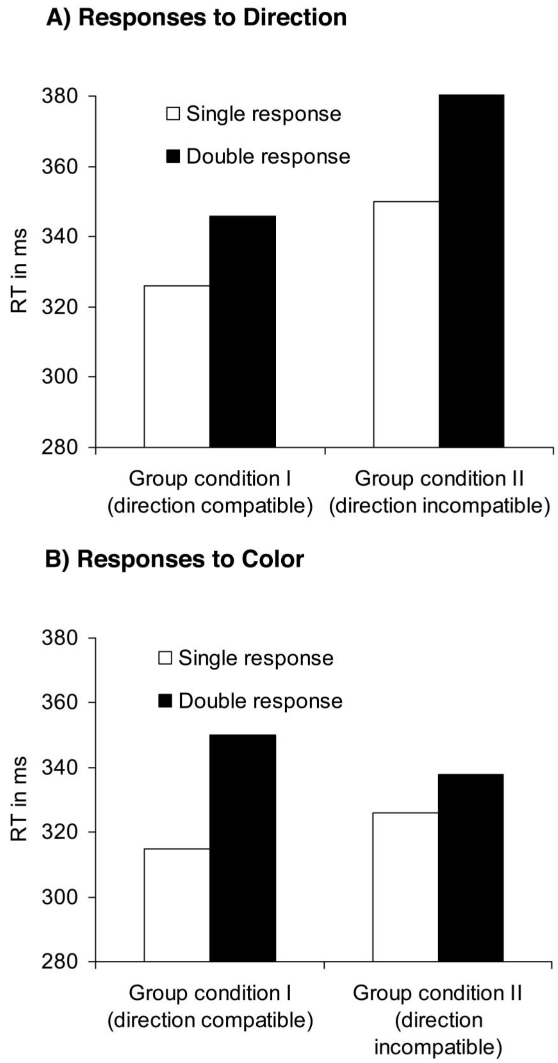


Figure 5. Results from Experiment 2. Responses to direction (A) and color (B) for single-response and double-response trials. RT = reaction time.

the effects of task conflict or action conflict were more pronounced. This time the two-sided *t* test showed a significant difference between RTs on single and double-response trials, $t(15) = 4.21$, $p < .001$, indicating that the effects of task corepresentation were more pronounced than the effects of action corepresentation.

To assess the combined effects of task corepresentation and action corepresentation, we analyzed performance of the color task in Group Condition I (other responds to compatible direction). As in Experiment 1, a two-sided *t* test showed a highly significant difference between RTs on single and double-response trials, $t(15) = 8.55$, $p < .001$.

The overall mean rate of omissions was 3.2% ($n = 32$). The same analyses as for RTs showed no significant differences (all ps $> .10$).

Discussion

Experiment 2 provided additional evidence for task corepresentation. The analysis of the direction task showed that RTs on double-response trials were slowed in both group conditions, indicating that a task conflict occurred in both conditions. The lack of a significant difference in Group Condition I in Experiment 1 was thus probably due to the small sample size. The analysis of the direction task also suggested that the slowing of RTs on double-response trials was more pronounced in Group Condition II (incompatible direction) than in Group Condition I (compatible direction). This result can be explained by the assumption that effects of task corepresentation and effects of action corepresentation are overadditive. In Group Condition II, no action conflict was present. In contrast, in Group Condition I, participants encountered both a task and an action conflict on double-response trials.

How can effects of task conflict and action conflict interact? The most likely explanation is that the task conflict manifests itself at the level of action selection. We assume that when a task rule is activated, a representation of the action that should be performed in response to a particular stimulus is activated. When the stimulus also activates this action through a direct link, the action is activated through two ways. Therefore, action conflict is more pronounced than when the action is only activated via a direct link.

Contrary to Experiment 1, there was a significant difference between the rate of omissions on double and single-response trials in Group Condition I. The fact that more omissions occurred on single-response trials could point toward a speed–accuracy tradeoff. However, the effect is numerically small, and 95% (single-response trials) and 97% (double-response trials) of the trials were entered into the RT analysis. Given that the slowing of RTs on double-response trials was consistently observed in Experiments 1 and 2 in the absence of any significant difference in omissions, it is unlikely that the difference between double and single-response trials in Group Condition I was exclusively due to a speed–accuracy trade-off.

The analysis of the color task suggests that the effects of task corepresentation were more pronounced than the effects of action corepresentation. It seems likely that in Experiment 1 this difference, which was numerically present, failed to reach significance owing to the small sample size. Finally, as in Experiment 1, we found evidence for combined effects of task corepresentation and action corepresentation.

Taken together, the pattern of results of Experiment 2 closely resembles that of Experiment 1, although participants did not receive any feedback about the other's actions. The results provide clear evidence for task corepresentation. It seems that overall, the effects were more pronounced in Experiment 2 compared with Experiment 1. This might have to do with the sample size. However, another (post hoc) explanation could also be that, owing to the lack of feedback, participants engaged more in thinking about the other's actions to make up for the lack of information. It seems possible that they internally simulated the other's action to maintain the full script of the situation that was specified by the instructions (Roepstorff & Frith, 2004). The lack of auditory and visual feedback may also account for the finding that RTs were generally slower in Experiment 2 compared with Experiment 1 (Sebanz et al., 2003).

General Discussion

The present study extends our knowledge about the uptake and integration of information about others' actions in situations that do not require interpersonal coordination. While previous studies have shown that features of others' actions are corepresented, our findings demonstrate that coacting individuals also form shared representations of tasks. Responses to one and the same stimulus varied depending on whether the stimulus was part of the other's task rule. Surprisingly, performance was influenced by knowledge about the other's task even when the other's actions could not be observed at all. This suggests that the way individuals conceptualize a social situation can determine how they integrate another's task in their own action planning.

The results showed decreased performance in response to stimuli requiring an action from the coactor. How can this finding of slower RTs on double-response trials be explained? One possible explanation is that a conflict occurs at the level of stimulus processing. It could be that the stimuli are given a specific meaning that reflects the task instructions. For example, if one knows that the other should respond to stimuli pointing right, these stimuli get the meaning of "being relevant to the other." While certain stimuli are only relevant for oneself, and others are only relevant for the coactor, stimuli requiring that two different task rules are applied carry the meaning of being relevant for oneself and for the other. Separating the two meanings might cause difficulty and result in a slowing of RTs.

However, the slowing of RTs on double-response trials could also reflect a conflict at the level of action selection. When a particular stimulus appears, it could—mediated by the task representation—activate a representation of the action to be performed. Thus, when a stimulus requires two different actions, two representations should be activated and cause an action selection conflict. This account is supported by the finding that effects of action and task conflict were overadditive, suggesting that a conflict occurred at the same level of processing.

Additional evidence for the action selection account is provided by a study in which we measured event-related potentials in pairs of participants performing the color task alongside each other (Group Condition III; Sebanz, Knoblich, Prinz, & Wascher, 2005). These results showed that response inhibition was significantly more pronounced on no-go trials in the group condition compared with the individual condition. This suggests that on no-go trials in the group (in which the coactor was to perform an action), an action representation was activated and it had to be suppressed. Further experiments are needed to clarify the nature of the conflict arising from stimuli that require a response from both actors. It is important to note that either of the two mechanisms discussed here is based on the assumption that the other's task is corepresented.

It seems to us that the observed effects warrant a representational account, in particular because the same effects of coacting were observed independent of whether individuals received feedback about the other's actions. Work on unintentional synchrony interpreted within a dynamical systems account suggests that the emergence of a coupled oscillator dynamic relies on visual information (Richardson et al., 2005; Schmidt & O'Brian, 1997). It remains to be seen whether interpersonal effects that result from the way task instructions are implemented can also be accounted for by dynamical systems principles.

The question of the mechanism underlying the observed effects is also related to the question of whether the same processes organize behavior within and between individuals (see, e.g., Schmidt, Carello, & Turvey, 1990; Schmidt & Turvey, 1994). Our findings speak to this issue in two ways. First, we propose that what happens on the level of action planning and control once a representation of somebody else's task has been formed is similar within and between individuals. The conditions we have in mind when making this claim are a two-choice condition (standard Simon task) in which one person is in charge of both action alternatives, and Group Condition III, in which each person is in charge of one action alternative (Sebanz et al., 2003). In the present study, we did not investigate a two-choice condition, but it is well known that a compatibility effect appears in such a condition.

The compatibility effect within individuals can be explained by the assumption that observed events and planned actions are commensurate and share a common representational domain (Hommel, Muesseler, Aschersleben, & Prinz, 2001; Prinz, 1997). The task-irrelevant spatial information automatically activates a representation of the spatially corresponding response (Kornblum et al., 1990). Responses are facilitated when the response required by the relevant stimulus feature corresponds to the response activated by the irrelevant spatial cue, and they are slowed when two conflicting action representations are activated. The compatibility effect between participants can be explained along the same lines assuming that the other's action is represented in a functionally equivalent way as one's own, so that observing or anticipating somebody else's action also activates one's own action representation (see Sebanz, Knoblich, Prinz, & Wascher, 2005). The compatibility effect in the group is smaller compared with the two-choice condition, because only one action alternative can actually be performed.

The similarity of the processes operating within and between individuals may be intriguing, but in our view, the most important finding of the present study was that individuals in the group were not behaving in the same way as when they were alone. We showed that the presence of another actor "afforded" the formation of a shared task representation. Thus, there seem to be processes that emerge only in a group setting and cannot be investigated when studying individuals in isolation.

Shared task representations may emerge only under certain conditions. For instance, direct stimulus–response mappings may be required. In our experiments, on seeing a green stimulus, the participant could immediately infer the corresponding action. When the stimulus–response rules are more complex and require an additional mental operation on perceiving the stimulus (e.g., a number classification task in which the number itself does not indicate what the corresponding action is), it may well be possible that individuals do not form a representation of the other's task but perhaps even try to separate their own task representation from the other's so as not to be disturbed. As a consequence, compared with an individual setting, their own representation might be modified rather than extended to include the representation of the other's task. Further experiments are needed to define the boundary conditions for representing others' tasks.

Also, it remains to be determined to what extent corepresenting a stimulus–response mapping is based on a representation of the other as an intentional agent. One possibility of how to conceptualize the link individuals make between certain stimuli and others' actions is to assume that they represent intentional relations (Moore, 1996). Barresi and Moore (1996) defined intentional relations as relations that involve an agent, an object, and the activity connecting agent to object. Applied to the group conditions of our experiments, the object would be a particular stimulus, and the activity connecting agent to object would be pressing the response button. Thus, sharing a representation of the other's intentional relation implies that upon perceiving a particular stimulus, a representation of the other's intention to act is activated. Support for the claim that a mental state of the other person is represented comes from a recent fMRI study that provides evidence that anticipating somebody else's actions following specific stimulus–response rules engages brain areas typically involved in ascribing mental states to others (Ramnani & Miall, 2004). However, in this study, monitoring the effects of the other's actions was part of the task. Whether mentalizing also occurs in the absence of the need to take the other agent into account and predict his or her actions remains to be investigated (see Sebanz & Frith, 2004; Sebanz, Knoblich, Stumpf, & Prinz, 2005).

Finally, we would like to speculate why individuals unintentionally and quasi-automatically tune-in to others, and, in particular, why they form shared representations when the context does not require it. We believe that one answer to this question can be found by analyzing the requirements of joint action. In many situations, individuals must coordinate their actions to reach common goals. It seems likely that the demands of joint action have shaped the human cognitive system in specific ways (cf. Clark, 1996; Knoblich & Jordan, 2002). In particular, individuals must be able to share others' representations (e.g., representations of their intentions and action goals, their perception of the current situation, etc.) to engage in successful joint action. Verbal communication is a powerful tool to develop shared representations but may be unavailable or too slow in some situations (Knoblich & Jordan, 2003). As a consequence, being able to infer others' action goals and intentions from observation of their actions may be of great advantage for interpersonal coordination (Wilson & Knoblich, 2005).

Our results suggest that individuals go even beyond picking up information from action observation. When provided with information about another individual's task (or, ultimately, intention), they seem to simulate the other's actions and fill in information that is not provided through direct observation. Forming a script of a situation that includes other actors even when coordination is not explicitly required may make sense because it prepares individuals for joint action. Alternatively, one could regard unintentional corepresentation as a sort of overflow of one's socially tuned mind. Given the benefits that are associated with the ability to predict others' actions, one may find oneself unable not to represent others' actions and intentions, even when this creates interference with one's own action planning and performance. Our brains might be operating somewhat like a single person constantly carrying an umbrella that is big enough for two—always ready to take others into account.

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