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What is Shared in Joint Action? Issues of Co-representation, Response Conflict, and Agent Identification

Dorit Wenke · Silke Atmaca · Antje Holländer · Roman Liepelt · Pamela Baess · Wolfgang Prinz

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Abstract When sharing a task with another person that requires turn taking, as in doubles games of table tennis, performance on the shared task is similar to performing the whole task alone. This has been taken to indicate that humans co-represent their partner's task share, as if it were their own. Task co-representation allows prediction of the other's responses when it is the other's turn, and leads to response conflict in joint interference tasks. However, data from our lab cast doubt on the view that task co-representation and resulting response conflict are the only or even primary source of effects observed in task sharing. Recent findings furthermore suggest another potential source of interference in joint task performance that has been neglected so far: Self-other discrimination and conflict related to agent identification (i.e., determining whether it is "my" or the other's turn). Based on these findings we propose that participants might not always co-represent *what* their partner is supposed to do, but instead co-represent *that* another agent is responsible for part of the task, and *when* it is his turn. We call this account the actor co-representation account.

Silke Atmaca and Antje Holländer contributed equally to this paper.

D. Wenke · S. Atmaca · A. Holländer (✉) · R. Liepelt · P. Baess · W. Prinz
Department of Psychology, Max Planck Institute for Human Cognitive and Brain Sciences,
Stephanstrasse 1a, 04103 Leipzig, Germany
e-mail: hollaender@cbs.mpg.de

D. Wenke
Department of Psychology, Humboldt University at Berlin, Berlin, Germany

R. Liepelt
Junior Group "Neurocognition of Joint Action", Department of Psychology,
Westfalian Wilhelms-University, Münster, Germany

P. Baess
Low Temperature Lab, Brain Research Unit, Aalto University School of Research and Technology,
Espoo, Finland

1 Introduction

Social interaction is a fundamental aspect of human life. We constantly engage in cooperative behavior and coordinate our actions in space and time with those of conspecifics. As a consequence, our actions are continually affected by the perceived social context, and we adjust our actions to the ad hoc requirements of our environment in order to generate the desired action effects all the time. In particular, we continuously observe our own and others' actions and action effects, and (re)act within the given social setting.

One such form of social interaction pertains to sharing a common task according to pre-defined rules, as in doubles games of table tennis. In double games of table tennis, each actor is responsible for only one part of the task (e.g., each player hits the ball only half of the time), and players take turns in performing their share of the task (in table tennis, they alternate in responding).

In experimental research on task sharing laboratory tasks are used that are more or less analogous to doubles games of table tennis. One binary choice task (e.g., when you see a square, press the left key, when you see a circle, press the right key) is typically split between two participants, with each of them only responding to one of the imperative stimuli, or targets (i.e., square vs. circle). In the joint condition, participants hence take turns in responding, depending on whether "their" target appears. Joint task performance is usually compared to (a) an individual condition in which the same single response go/nogo task (e.g., only respond when a square appears, do not respond to a circle) is performed alone, and (b) to an individual condition in which each participant performs the whole, binary choice task alone.[1] Applied to the table tennis example, analogues of these experimental conditions would be games in which an individual player (a) plays a doubles game of table tennis, taking turns with another player (joint single response go/nogo task); (b) plays alone, but hits the ball only when it would be his/her turn in the doubles game (i.e., every second time, whereas the ball drops to the ground when it is not her/his turn (individual single response go/nogo task)); (c) plays a normal (non-doubles) game of table tennis trying to hit all balls alone.

In what sense does the task sharing paradigm study joint action or even joint intentionality? When we examine this question in conceptual terms the answer turns out to be ambiguous. On the one hand, what is obviously joint in the joint condition is participants' understanding of them taking part in a dyadic scenario and sharing a joint task with a partner in a division-of-labor mode. This is actually the way in which both the setting and the task are explained to them in the instructions (unlike in the individual condition in which individual participants perform their task in isolation, without ever realizing that the task they are performing could also be regarded and performed as an individual share of a joint task in which somebody

[1] Here and in the following we use the term single response go/nogo task to refer to tasks in which participants have only one response "alternative", and are either required to respond (go) or to withhold the response (nogo), depending on the task rules, and hence the stimulus presented on a given trial. In contrast, we use the term binary choice task when participants respond *on each trial* by choosing the appropriate response from two response alternatives. Finally, the term binary choice go/nogo task refers to tasks in which participants respond to some stimuli by choosing between two response alternatives assigned to certain stimuli (go), but have to refrain from responding to other stimuli (nogo).

else is involved). Thus, while their overt responses are identical in the joint and individual conditions, participants' understanding of their doings is likely to be different: taking turns in responding with one's partner versus taking turns in responding/withholding (in the joint and individual condition, respectively). On the other hand, what is less obviously joint in the joint condition is how participants control their behavior on individual trials during task performance. Once they have understood and implemented the rules of the task they could, from then on, in principle, act entirely independent from each other without taking their partner's actions into account. This is because the task rules and the imperative stimulus presented on a given trial unambiguously specify whose turn it is. The joint condition may thus be seen to invite a 'joint' understanding of performance at the personal level of task representation, without, necessarily implying that that understanding must be grounded in the 'joint' workings of the machinery for action control.

However, findings from research investigating task sharing strongly suggest that task sharing affects *performance* on a given trial, and hence how actions are controlled, although no cooperation in the strict sense is required (i.e., adjusting parameters such as timing or force of one's own actions in order to coordinate actions such as lifting and carrying a table with another person). In particular, results from this line of research have revealed marked differences between joint performance of single response go/nogo tasks compared to individual performance of the same task, at least when the co-actor is believed to be an intentional agent (Atmaca et al. 2011; Tsai et al. 2008; see Section 2 below). Moreover, the effects obtained with single response go/nogo tasks in joint task settings seem to closely resemble effects obtained when one person performs the whole binary choice task alone.

Based on such findings (see Section 2, for a detailed description of the tasks used, the results obtained with these tasks, and the conclusions based on these results), it has been proposed that humans in joint task settings somehow co-represent their co-actors' task shares and/or actions as if they were their own, so that joint single response go/nogo task performance is functionally similar to performing the individual binary choice task. However, an open question that still remains is what exactly co-representation entails.

The aim of this article is to provide a critical review of the dominant co-representation account of previous findings. In doing so, we find it helpful for conceptual clarity to distinguish between the assumptions and interpretations regarding what is actually co-represented in joint task settings on a *representational level*, on the one hand, and the mechanisms and processes that lead to joint action effects during joint task execution on a *performance level*, on the other hand. Co-representation in the first sense pertains to how participants represent the task within the joint task context differently from the individual task setting, partly even before they encounter the first stimulus to which one of them has to respond. In contrast, co-representation in the latter sense refers to the assumed processes that evoke joint action effects during task performance. The assumed processes leading to joint action effects during task performance depend on the assumed contents of (co-) representation.

We argue that the dominant view of what is co-represented on the representational level proposes task co-representation. The *task co-representation account* holds that, in joint task settings, participants co-represent the other person's task share. That is, they co-represent the other person's stimulus-response (S-R) mappings in their own representation of the task as if they were their own. The proposed function of such task co-representation is that each actor is able to predict and simulate what the other person is supposed to do under certain stimulus conditions (e.g., Sebanz et al. 2006; Sebanz and Knoblich 2009; Van Schie et al. 2004). According to this account, players in doubles games of table tennis anticipate (and simulate) whether their partner should respond with, say, a flip or a top spin under given ball angle conditions when it is the partner's turn. In case of response interference tasks typically used to study task sharing in psychology labs (see Section 2, below), co-representation of task shares predicts *conflict* between simultaneously activated representations of *responses* when stimuli assigned to the co-actor's *response* are presented as irrelevant stimuli together with a target stimulus that requires a different response by the actor. Section 2 provides an overview of findings that gave rise to the task co-representation view that task shares are co-represented in joint task settings, leading to response conflict during joint single response go/nogo task performance.

In Section 3 we present data from our lab that are difficult to reconcile with the task co-representation account and the response conflict explanation of joint action effects. These experiments were designed to further test the task co-representation account. In particular, we sought to provide evidence for task co-representation when participants performed *binary choice go/nogo tasks* in joint task settings. However, these experiments consistently failed to show evidence in favor of task co-representation. Although we are aware that null-findings are notoriously difficult to interpret, we argue that the consistency of null findings across different tasks and experiments suggests that *task* co-representation and resulting response conflict may not be the only, or primary, source of joint (interference) effects typically observed in joint task settings.

Finally, in Section 4, we present data that suggest another potential source of interference in joint task performance that has been neglected so far. These data suggest that conflicts concerning agent identification (i.e., agent discrimination: determining whether it is "my" turn or "the other's" turn on a given trial) lead to interference effects observed during joint task performance, instead of response conflict due to co-representation of task shares and actions. Based on these findings we propose an alternative account of what is shared in joint task settings. According to this account—the *actor co-representation account*, participants in joint task settings do not (co-)represent *what* exactly the other person is supposed to do under given stimulus conditions (i.e., the co-actor's S-R mappings), nor do they vicariously activate and predict their partners' responses upon seeing the other's stimuli. Instead, the actor co-representation account assumes that participants co-represent *that* another person is responsible for the complementary task share, and *when* the other person has to respond (i.e., the stimulus conditions under which it is the co-actor's turn). Applied to the table tennis example above this account suggests that players do not co-represent and anticipate whether their partner should respond with a flip or a top spin, but merely co-represent that their partner is supposed to hit the ball on some trials, and when (e.g., every second time the ball arrives). We argue that many of the existing findings previously interpreted as support for the task co-representation account are also consistent with the actor co-representation account.

2 Task Co-representation and Response Conflict in Task Sharing

As outlined above, in most existing task sharing studies participants respond to different targets within a common interference task, thereby each performing a single response go/nogo task. Typically, joint single response go/nogo task performance is compared to individual performance of the same task, as well as to individual performance of a binary choice task (see footnote 1 for definitions of the terms used to refer to the different types of tasks/conditions).

Many demonstrations of co-representation in task sharing have used variants of the Simon task (e.g., Simon 1990; Simon et al. 1970). In the binary choice Simon task, individual participants perform left and right key press responses to arbitrary stimulus attributes such as shape or color. Stimuli are randomly presented on the left or the right of the screen. Although stimulus location is completely irrelevant, it leads to response interference effects: responses are typically much faster and less prone to errors when stimulus position and response location correspond (i.e., when stimulus position and response location are compatible) than when they are different (i.e., when stimulus position and response location are incompatible). This finding is referred to as the Simon effect (De Jong et al. 1994; Lu and Proctor 1995; Simon and Rudell 1967).

The most widely accepted explanation of the Simon effect holds that (automatic) translation of relevant stimulus attributes to required responses via a controlled route (Kornblum et al. 1990), or activation of short-term memory S-R links established during instruction (Tagliabue et al. 2000), is influenced by the dimensional overlap between features of the irrelevant stimulus attribute (e.g., left vs. right stimulus position) and features used for representing the response (e.g., left vs. right response location; De Jong et al. 1994; Hommel et al. 2001; Kornblum et al. 1990; Zhang et al. 1999). According to this view, irrelevant stimulus features such as left-right stimulus position automatically activate (i.e., prime) their corresponding (left–right) responses whenever stimuli and responses are represented along the same or related dimensions. Response priming facilitates responding if the correct response is activated, but leads to response conflict when the target stimulus requires the selection of the non-corresponding response. Response conflict delays responding because it needs to be resolved before the correct response can be selected.

The Simon effect is usually not observed when an individual participant performs a single response go/nogo response. Single response go/nogo tasks require participants to respond to only one of two target stimuli (with one pre-defined response), and to withhold responding when the other target stimulus appears. Reduced interference from irrelevant stimuli in single response go/nogo tasks has been attributed to differences in how single responses and binary choice responses are represented. Specifically, it has been proposed that participants do not usually spatially represent their responses as being left (vs. right) when they perform single response tasks (Ansorge and Wühr 2004), but instead they might simply represent their response options as respond/withhold response. As a consequence, spatial stimulus attributes no longer overlap with response representations, and therefore do not automatically activate (i.e., prime) responses.

Sebanz et al. (2003) were the first to exploit this pattern of findings (interference effects in individual binary choice task performance, but not in individual single response go/nogo task performance) for investigating task sharing, and to demonstrate that interference effects re-appear in single response go/nogo task performance when participants share a choice task such that each participant is responsible for complementary parts of the task. They compared three conditions of the Simon task. In their individual go/nogo condition, participants performed go/nogo responses that required a response to one stimulus attribute (e.g., a red ring on a left- or right-pointing finger; go-response), whereas responses to the other stimulus (e.g., a green ring on a left- or right-pointing finger) had to be withheld (nogo-"response"). In the joint go/nogo task, two participants sat alongside each other and performed complementary go/nogo tasks (e.g., one participant responded to red, the other to green). Hence, the joint and the individual go/nogo conditions only differed with respect to the presence or absence of a co-actor who performed the complementary go/nogo task. In addition, Sebanz et al. (2003) included a standard Simon task in which participants were sitting alone centrally in front of the screen, reacting with binary choice responses to both stimulus colors. In all conditions, the irrelevant spatial stimulus attribute was the pointing direction of the finger (left vs. right) on which the colored ring (the target) appeared.

Replicating previous results, Sebanz et al. (2003) found a Simon effect in the binary choice Simon task, but not in the individual single response go/nogo task. However, a Simon effect also appeared in the joint single response go/nogo condition. Based on these findings, the authors concluded that performing a single response go/nogo task in a joint task setting is functionally similar to performing a binary choice task alone. Specifically, in close analogy to the interpretation of interference effects observed in individual binary choice task performance, they suggested that activating one's own as well as the co-actor's responses on trials in which relevant and irrelevant stimulus attributes lead to response conflict, thereby delaying responding in the joint, but not the individual, condition of the single response go/nogo task. Several studies have replicated (e.g., Tsai et al. 2006) and extended (e.g., Atmaca et al. 2008; Guagnano et al. 2010; Sebanz et al. 2005) Sebanz et al.'s (2003) initial findings using Simon-like tasks. The majority of these studies investigated the impact of environmental conditions on the occurrence of the joint Simon effect by manipulating, for instance, the visibility of the other's actions (Sebanz et al. 2003), the absence vs. presence of the co-actor in the same room (Tsai et al. 2008; Welsh et al. 2007), cooperative vs. competitive setting (Ruys and Aarts 2010), and the quality of the relationship with the co-actor (Hommel et al. 2009). But what do these findings tell us about the *contents* of co-representation? We argue that the joint Simon effect is consistent with two slightly different accounts of what is co-represented on a representational level—an action co-representation account and a task co-representation account (also see Sebanz et al. 2005 for a similar distinction). Both action co-representation and task co-representation would lead to response conflict during joint task performance.

According to the *action co-representation* account, joint task settings (in which in which participants sit alongside each other and typically press laterally arranged response keys) simply (re-)introduce spatial response coding. For example, a participant who sits to the left of her co-actor, and operates the key in front of her (i.e., the left of the two keys), might represent her own single response as the left response in the joint task setting, and the partner's response as the right response. As a consequence, they would represent the other person's action as, say, right, and their own as left, thereby establishing dimensional overlap between irrelevant stimulus features (i.e., stimulus position) and features used for response coding. Since spatial response coding is sufficient for the Simon effect to occur in individual single response go/nogo tasks (Ansorge and Wühr 2004), action co-representation could explain the joint Simon effect. Note that the action co-representation account does not require co-representation of the stimulus conditions under which the co-actor is supposed to respond (also see Guagnano et al. 2010, and Liepelt et al. submitted).

In contrast, according to the second, *task co-representation* account of the joint Simon effect, participants do not only co-represent their partner's action, but also co-represent the stimulus conditions under which his or her action has to be performed (i.e., his or her S-R rules or mappings). As outlined in the introduction, task co-representation assumes that participants in joint task settings co-represent their co-actor's task share, or S-R mappings (e.g., red ring: press right) in a functionally similar way as their own task share (e.g., green ring: press left). Task co-representation implies that stimuli assigned to the other person lead to vicarious response activation of the other's response in the actor's motor system, thereby allowing action-related simulations and predictions (e.g., Sebanz and Knoblich 2009). Since task co-representation involves spatial (left–right) coding of responses, it can also account for the joint Simon effect.

Whereas studies using the joint Simon task cannot (easily) distinguish between action co-representation and task co-representation as the source of the response interference effect, other studies using different tasks and interference effects arguably can (e.g., Atmaca et al. 2011; Ramnani and Miall 2004; Sebanz et al. 2005). They seem more consistent with the task co-representation view that joint task settings induce co-representation of task shares (S-R mappings).

For example, Atmaca et al. (2011) used an Eriksen flanker task (Eriksen and Eriksen 1974) to investigate task sharing. Their study included three task conditions, too: An individual binary choice task condition, a joint single response go/nogo task in which the individual binary choice task was divided between two participants that sat alongside each other, and an individual condition, in which the same single response go/nogo task was performed alone.

In the individual binary choice flanker condition, individual participants pressed the left or right key, depending on the identity of a target letter (e.g., they pressed the left key when the letter was H or K, and the right key when the letter was C or S). Target letters were presented centrally in the middle of a display. They were surrounded (flanked) by distracter letters that could be a) the same as the target (identical trials, e.g., HHHHH), b) assigned to the same response (compatible trials, e.g., KKHKK), c) assigned to the opposite response (incompatible trials, e.g., SSHSS), or d) not linked to any response (neutral trials, e.g., UUHUU). Participants' reaction times (RTs) varied depending on the target-flanker combination: RT identical < RT compatible < RT neutral < RT incompatible, replicating the well-known Eriksen flanker effect (Eriksen and Eriksen 1974).

The prevailing explanation for the flanker effect is that flanker letters activate their associated responses, leading to response conflict when the target and the flankers are assigned to different responses (Coles et al. 1985; Grice and Gwynne 1985; Sanders and Lamers 2002). Unlike the Simon task, there is no dimensional overlap between (irrelevant) stimulus attributes (e.g., stimulus position) and responses (e.g., response location) in the flanker task. Instead, response conflict in the flanker task has been attributed to parallel (automatic) activation of representations (associations or links) of arbitrary stimulus-response (S-R) rules (cf. Hommel 2000).

In the joint and in the individual versions of the task, Atmaca et al. (2011) divided the binary choice flanker task into two single response go/nogo tasks, and compared performance on the joint single response go/nogo task with an individual single response go/nogo condition in which participants worked alone. Incompatible flankers were assigned to the co-actor's response in the joint task setting, but were not assigned to any response in the individual task setting. Neutral flanker letters (i.e., letters that were not assigned to any response and never appeared as targets) were included in both the joint and the individual task setting. This was done in order to control for a general speeding up of responses often observed in joint task contexts, which is known as social facilitation (e.g., Aiello and Douthitt 2001; Guerin 1993; Zajonc 1965). Figure 1 provides an overview of the task. Of particular interest was the impact of social setting (joint, individual) on the slowing of reactions on incompatible trials compared to the neutral baseline.

Results showed a joint flanker effect, as indicated by enhanced RT differences between incompatible and neutral trials in the joint condition compared to the individual condition. In analogy to the response conflict interpretation of the individual binary choice condition of the flanker task that explains the flanker

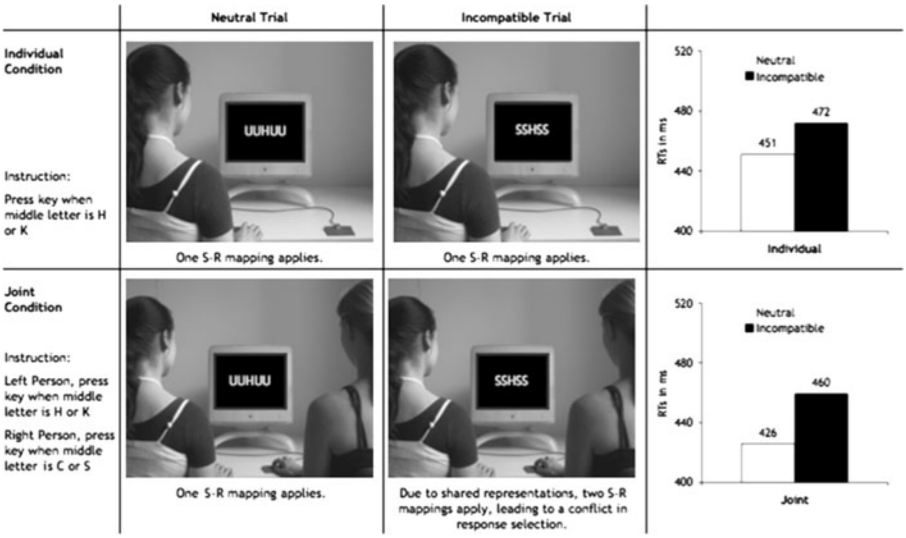

Fig. 1 The first two panels (from *left to right*) of the first row depict neutral and incompatible trials in the individual condition of the single response go/nogo flanker task. Second row (*first two panels*): neutral and incompatible trials in the joint condition of the single response go/nogo flanker task. According to the task co-representation account, no response conflict occurs on neutral trials from the perspective of the left person (in the joint or the individual condition *Panel 2*, *both rows*). The same is true for incompatible trials in the individual condition (*second panel, first row*). In contrast, on incompatible trials in the joint condition (*second panel, second row*), two task rules apply, due to co-representation of S-R mappings. The resulting response conflict slows RTs on incompatible trials of the joint compared to the individual condition (see *third panel*). Note that RTs on neutral trials (*white bars*) are regarded as baseline. Compared to the neutral baselines, RTs on incompatible trials (*black bars*) are more impaired in the joint condition than in the individual condition (*right panel, lower row* vs. *right panel, upper row*)

interference effect with parallel (automatic) activation of S-R mappings by the target and the flankers, Atmaca et al. (2011) interpreted this finding as indicating increased response conflict in the joint condition. According to this explanation, participants co-represented the other's S-R mappings as if they were their own, leading to response conflict when the other's stimuli appeared as flankers on incompatible go-trials (see, e.g., Sebanz et al. 2005, for related findings).

To summarize, (behavioral) research on task sharing so far has mostly used response interference tasks like the Simon task or the Eriksen flanker task. When a binary choice task is split between two participants such that participants perform complementary shares of the task, similar interference effects in RTs and errors are observed as in the individual binary choice task. This is typically not the case when the same single response go/nogo task is performed by each participant alone. The dominant account of such findings is that, in joint task settings, each participant represents the other's task share (S-R mappings) in a functionally similar way as his/her own. Co-representation of the other S-R mapping in turn leads to vicarious activation of the other's responses when the other's stimuli appear during joint task performance. When an interference task like the Simon task or the Flanker task is divided between two co-actors, participants therefore experience conflict among self- and other-generated responses in a way that closely resembles response conflict among two self-generated responses. Thus, response conflict is the assumed source of interference effects in RTs. The main function attributed to task co-representation and vicarious response activation seems to be that actors can predict their co-actor's action and action effects (e.g., Sebanz et al. 2006; Sebanz and Knoblich 2009; Vesper et al. 2010).

In the next section, we present data from experiments in which we attempted to test further predictions of the task co-representation account with respect to joint binary choice go/nogo task performance. The results from these experiments cast doubt on the view that conflict between competing *responses* is the only (or even the primary) source of joint action effects.

3 Task Sharing with Binary Choice Go/Nogo Tasks

In this section, we present results from experiments that further tested the task co-representation account. In particular, we attempted to provide evidence of shared S-R representations in situations that required each participant to perform binary choice responses instead of single responses, using their left and right hands as effectors. As in the original task-sharing studies described above, participants only responded to some stimuli and not to others. That is, they performed go-nogo tasks that required responding to some stimuli, but not to others (in most experiments, they required responses to complementary target stimuli), and joint task performance involved turn taking. Following the logic of previous experiments, joint task performance was compared to individual performance of the same binary choice go/nogo task.

The rationale behind these experiments was as follows: If the (interference) effects observed in joint task settings are indeed due to task co-representation (i.e., representation of the other's S-R mappings) and ensuing vicarious response activation of others' responses upon encountering their stimuli, then we should expect joint interference effects to depend on *which* of two response alternatives becomes activated when the other's stimuli are presented.

Experiments 1 and 2 relied on interference tasks similar to those reviewed in the previous section. They focus on the impact of (irrelevant) stimuli referring to the co-actor's responses that are presented simultaneously with (Experiment 1), or previous to (Exp. 2a & b), an actor's target, on the actor's responses on go-trials. For instance (see Exp. 1 below), we expected to find interference effects (i.e., slowing of RTs) in the actor's responses when the response required by the target (e.g., "left" in a left-right binary choice task) differed from the co-actor's response (e.g., right in a left-right binary choice task) to a stimulus that appeared as distracter, compared to when both stimuli required the same response (e.g., a left response by the actor and the co-actor).

In Experiment 3 we investigated whether we would find evidence for vicarious response activation in motor-related EEG (electroencephalography) potentials. In particular, we were interested in the occurrence of motor related components such as the lateralized readiness potential (LRP) on trials when it was the co-actor's turn. If indeed participants co-represent their partner's' S-R mappings and vicariously activate them when their stimuli are presented, then we should find evidence for motor activation in those EEG components on nogo-trials that depend on which response the co-actor had to perform in response to his/her stimulus.

To preview, all of these experiments consistently *failed* to provide evidence for vicarious response activation, and hence, for task co-representation. Of course, we are aware that it is problematic to draw strong conclusions from null results. Nevertheless, with regard to the sheer volume of failed experiments and the consistency of null results across different paradigms, we argue that they should not be ignored. We believe that, taken together, they argue against task co-representation and response conflict as the only source of joint interference effects in task sharing contexts.

3.1 Experiment 1: Joint Binary Choice Go/Nogo Flanker Task Performance

Following up on Atmaca et al.'s (2011; see previous section) study with single go/nogo responses, we designed an adapted version of the joint Flanker task, which required binary choice go/nogo responses by each participant in response to colored circles. Stimuli were an array of three colored circles. These stimuli were presented on a horizontal screen that was positioned between two participants facing one another (see Fig. 2). Each participant (N=32) was responsible for two response keys, responding to two different colors. For instance, Person A responded to blue with a left key press and to red with a right key press, while Person B responded to yellow with a left key press and to green with a right key press. The color of the middle circle was the target and determined whose turn it was.

This setup allowed us to test S-R specific flanker compatibility effects. Different from the joint single response go/nogo flanker task with only one response alternative for each actor (Atmaca et al. 2011), flankers in the joint binary choice go/nogo flanker task with two response alternatives for each actor could be either compatible or incompatible on both, an intra-individual and an inter-individual level in the joint setting. In the *intra-individual* conditions, the flanker colors were assigned to the same person as the target and either signaled the same response as the target (intra-individual compatible flanker condition) or the alternative response

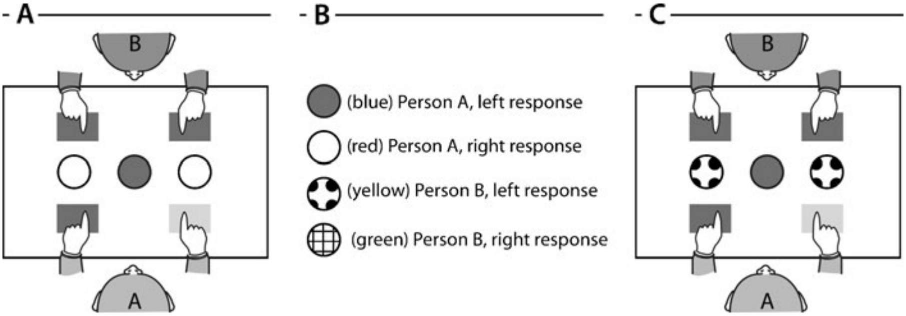

Fig. 2 Examples of 1.) an intra-individual incompatible trial in the joint task setting (**a**), and 2.) an anatomically compatible/spatially incompatible other-flanker trial in the joint inter-individual condition (**c**), for a given set of mappings of colors to participants and responses (**b**). Participants faced each other and placed their hands on the left and right response keys mounted on top of a flat screen. Stimuli appeared at the centre of the flat screen

option (intra-individual incompatible flanker condition; see Fig. 2, panel A, for an example of a intra-individual response-incompatible trial).

In the *inter-individual* conditions, the colors that appeared as flankers "belonged" to the other person. The other person's flanker stimuli could either signal the same response as the one required by the agent (e.g., "left"; inter-individual compatible flanker condition), or they signaled different responses (e.g., "left" vs. "right"; interindividual incompatible flanker condition). We were particularly interested in the inter-individual flanker conditions. If participants indeed co-represent their co-actor's S-R mappings, target responses should be affected by whether the flanker color was mapped to the co-actor's left or right response. In particular, we expected that co-representing the co-actor's S-R mappings should lead to activation of the co-actor's (left-right) responses when their stimuli appeared as flankers. Because the representation of the co-actor's responses overlaps with the actor's responses on go-trials (both being represented as left vs. right), we predicted that response co-activation would lead to response conflict, and hence, to delayed responding in the inter-individual incompatible flanker condition.

By placing the subjects such that they faced each other, with their effectors (and the response keys) placed on the flat screen between them (see Fig. 2), we furthermore sought to disentangle whether participants would represent the other person's S-R mappings in an allocentric or egocentric mode (cf. Holländer et al. 2011). We predicted that the mode of task co-representation should determine the direction of the inter-individual flanker compatibility effect. The allocentric mode refers to co-representation from the co-actor's perspective (inter-personal perspective). If participants allocentrically co-represent their co-actors' S-R mappings, one would therefore expect slower responses (i.e., response conflict) when the target and flanker colors are assigned to opposite effectors (e.g., the target color requires a right response by the actor, whereas the flankers are assigned to the co-actor's left hand) than when both targets and flankers are mapped to the same effectors (e.g., both the target and the flanker color signal a left hand response). That is, according to the allocentric mode there should be an "anatomical" flanker compatibility effect.

In contrast, egocentric mode refers to action co-representation from one's own perspective (intra-personal perspective). Egocentric co-representation predicts that target responses should be faster when the color of the co-actor's flanker would require a response on the same side of the screen than if the flanker signals a response on the other side of the screen. That is, one would expect a spatial compatibility effect in the opposite direction to what would be expected with allocentric co-representation. Fig. 2 (panel C) depicts an example of an anatomically compatible/spatially incompatible inter-individual trial.

Unexpectedly, we did not find a flanker compatibility effect in the inter-individual condition that depended on the co-actor's S-R mapping, and hence, response side, thus neither providing evidence for allocentric nor egocentric co-representation of the other person's S-R rules. Interestingly however, responses were generally faster when targets were flanked by the actor's own colors in the intra-individual conditions than in the inter-individual conditions in which the flankers belonged to the co-actor (own flanker advantage). One possible explanation for this effect is that flankers assigned to one's own responses might facilitate agent identification (i.e., determining whether or not it is "my" turn) compared to situations in which targets and flankers signal responses by different agents.

Furthermore, at least for a subgroup of participants that reached high empathy scores on the Bamberg Empathy Questionnaire developed by S. Enz, C. Zoll and H. Schaub (cf. Enz 2009), the own flanker advantage was larger in the joint setting than in the individual setting in which each participant performed his/her binary choice go/nogo task alone. Like other, more widely used empathy questionnaires such as the Interpersonal Reactivity Index (Davis 1980; 1983), the Bamberg questionnaire conceptualizes empathy as a set of separate but related constructs reflecting the tendency .to cognitively and affectively put oneself in the shoes of others and to spontaneously adopt their psychological point of view (Davis, 1980). Unlike other questionnaires however, the Bamberg questionnaire does not only include subscales for measuring cognitive empathy (assessing, for example, perspective taking) and affective empathy (e.g., empathetic concern and personal distress related to other people's suffering), but also a subscale called "ideomotor" empathy, measuring the tendency for motor contagion through action observation (e.g., the tendency for making kicking movements induced by watching a soccer game involving kicking movements on TV; see, e.g., Prinz 1997, for an elaboration of ideomotor theory). The finding that participants with high empathy scores (both, overall scores and scores on the ideomotor subscale alone) showed a stronger own flanker advantage in the joint than in the individual task setting suggests that participants who readily put themselves in the shoes of others experience increased difficulty (or conflict) in agent identification and agent selection when performing the binary choice go/nogo task together with a co-actor, compared to when performing the same task alone. We will discuss the implications of this finding in more detail in Section 4 and in the discussion part of this paper.

3.2 Experiment 2a and 2b: Joint Task-Switching

In Experiments 2a and 2b, we compared individual and joint task-switching performance, using switch costs as the main dependent variable. The aim was to investigate the impact of vicarious response activation and selection on a previous nogo-trial N-1 on performing a current go-trial N.

In the standard task switching paradigm, individual participants have to respond according to one of two sets of task rules that both involve binary choice responses (e.g., responding left vs. right to the shape *or* the color of ambiguous color/shape stimuli). One standard finding in task switching is that responses are slower when participants have to switch to a different task on consecutive trials (e.g., from a form judgment on trial N-1 to a colour judgement on trial N) than when the task repeats across trials. This effect has been referred to as switch costs (e.g., Rogers and Monsell 1995). At least in the case of overlapping tasks (e.g., the color *and* the shape task require responding to the same colored shape stimuli by pressing either a left or a right key), switch costs seem to partly depend on response conflict elicited by competing task rules and on conflict resolution on the *previous* trial (cf. Schuch and Koch 2003). Thus, switch costs assess interference across trials instead of, or in addition to, interference due to irrelevant stimulus attributes that are presented together with the target stimulus within a given trial.

Consistent with this view, no such switch costs show up in the standard switching paradigm when the previous trial did not require a response. That is, when a nogo signal was presented together with the target, indicating that participants were not supposed to respond on trial N-1 (Schuch and Koch 2003; Koch and Philipp 2005). This finding underscores the importance of response activation and selection on trial N-1 for obtaining switch costs on trial N.

In our shared task switching experiments, we compared switch costs when participants switched between binary choice go/nogo tasks in a joint condition in which two participants were seated alongside each other and took turns with individual performance of the same task. We sought to exploit the finding that switch costs in individual task settings are only observed following go-trials when participants selected a response, but not following nogo trials where no response selection was required. We reasoned that if participants in joint task settings (a) co-represent the other person's S-R mappings, and (b) vicariously activate and select the other person's response when his/her stimulus appears, then we should expect switch costs following nogo trials (that is, trials in which it was the other person's turn) to closely resemble switch costs following (own) go-trials.

In *Experiment 2a*, we compared joint and individual performance when participants switched between a form task (e.g., diamonds—press right; squares—press left) and a color task (e.g., red—press right; blue—press left). Both actors responded to each stimulus of each task by using their left and right hands, thereby performing binary choice go/nogo tasks according to the task rules (color or shape) that were relevant on a given trial. The background on which the target stimulus appeared served as a person cue that indicated whose turn it was. In the joint task setting, go trials for one participant were nogo trials for the other, and vice versa. In the individual condition participants performed the same binary choice go/nogo task alone. Figure 3 provides an example of typical events within and across trials in the joint setting of Exp. 2a.

As outlined above, we were particularly interested in trial sequences that involved transitions from nogo- to go-trials (i.e., person switch trials). In the individual condition, we expected to replicate previous findings of task switch costs following go-trials, but no switch costs following nogo-trials. In contrast, in the joint condition, we expected switch costs to occur after both go-trials (person repetitions) and nogo-trials (person switches).

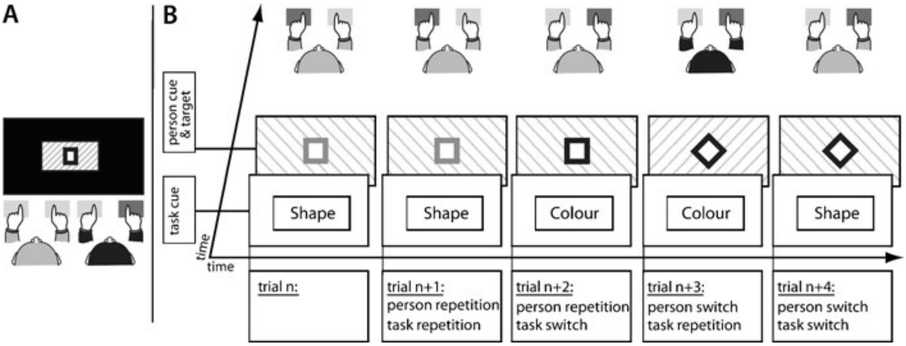

Fig. 3 Example of a typical sequence of trials in the joint condition of the task-switching experiment. **a** Participants sat alongside each other in front of one computer monitor. The background on which the colored shapes were presented determined whose turn it was. **b** A task cue was presented 300 ms prior to the stimulus display containing the person cue and the target. The task cue indicated whether to perform the color task or the shape task, each of which had two stimulus and response alternatives for both actors

Results from 16 participants did not confirm this prediction: There were no task switch costs following nogo-trials, independent of social setting. Switch costs (of similar size) only occurred after go-trials in both settings. The only potentially interesting effect in Exp. 2a was that responses on go-trials were generally slower following nogo-trials than following go-trials (nogo-go slowing, see below), indicating that responding is easier when it is "my" turn on two successive trials than when this is not the case. Error data closely resembled reaction time results.

Experiment 2b replicated these (null) findings regarding switch costs following nogo-trials in the joint vs. individual condition with a new sample of 16 participants, using different tasks (magnitude and parity judgments on numbers, with left and right key press responses required on both tasks), different cues (colored shapes surrounding target numbers, with shape signaling the task to be performed, and color serving as the person cue), and different timing of events (either 0 ms or 1,000 ms between onset of the task/person cue and the target stimulus).[2] Again, no switch costs were observed following nogo-trials, regardless of social setting (and timing of events). We argue that the consistency of null findings across Exps. 2a and 2b provides evidence against task co-representation and vicarious response activation during joint task switching. The fact that participants were required to respond to the same stimulus alternatives (e.g., square and diamond in the shape task of Exp. 2a) might have further discouraged task co-representation in these experiments (cf. Lam and Chua 2009).

Interestingly however, Exp. 2b also replicated the effect of nogo-go slowing. In addition, there was an almost significant tendency in Exp. 2b for nogo-go slowing to be more pronounced in the joint (42 ms) than in the individual setting (21 ms; $p=.065$). One possible interpretation for this finding is that determining whether it is "my" turn on a given trial is more difficult in joint than in individual task contexts, leading to enhanced reliance on information pertaining to whose turn it was on the previous trial when determining who has to respond on the current trial (with repetitions being

[2] We thank Andrea Philipp for providing the data of this experiment.

easier). We will return to this possibility in Section 4 and the discussion part of this paper.

3.3 Experiment 3: Vicarious Response Activation on Nogo-trials?

In an EEG study we attempted to provide direct evidence for vicarious response activation on nogo-trials when participants perform binary choice go/nogo tasks together, and hence, for task co-representation. This EEG study measured foreperiod LRPs indicative of vicarious response preparation processes on nogo-trials. The experimental design was based on a study by Leuthold et al. (2004) who investigated action preparation processes measured as foreperiod LRPs. This design allowed us to investigate vicarious response activation when the co-actor's stimuli appeared on nogo-trials, without using an interference task.

Participants (N=16) in Experiment 3 sat beside each other (see Fig. 4) with their hands placed on response keys in front of them. They saw pictures of cups of different colors with handles on the left vs. right side. In the beginning of each trial, the cups were depicted without the handle. The color of the cup determined whose turn it was (e.g., blue cup—left participant; green cup—right participant; orange cup—neither). Next, a handle appeared on the left or right side of the cup, indicating the required response. However, action execution had to be withheld until the horizontal bar beneath the cup disappeared (go-signal). The task was to release one of the keys and to perform a pseudo-grasping movement with the hand on the side of the handle, as if to catch the cup. The catching movement had to be performed within a certain time frame, followed by performance feedback (picture of intact vs. broken cup). Figure 4 shows a schematic of the events within a given trial.

Separating the person cue (cup color) from the "target" (handle side), and presenting a delayed go signal (removal of the bar beneath the cup) allowed us to study processes of action preparation that were unconfounded by processes of agent identification and action execution. In particular, our analysis focused on foreperiod LRPs in the interval between handle presentation and go-signal. Based on previous findings (Leuthold et al. 2004) we expected to find such foreperiod LRPs indicative of preparing left vs. right motor responses on go-trials (i.e., when participants knew that it was their turn). More importantly, if participants indeed co-represent the other person's share of the task, foreperiod LRPs should also show up on nogo-trials when the handle appeared on a cup the color of which signaled the other person's turn. Such LRPs on other person nogo-trials would indicate that the other's stimuli elicit vicarious motor preparation that allows prediction of the other's future actions. However, contrary to expectations, LRPs were only observed on go-trials (i.e., for cups presented in the actor's own color), while they were absent on nogo-trials.[3]

[3] We also analyzed the CNV because previous findings suggests that the late part of the CNV also reflect anticipatory motor preparation when preparing to act oneself as well as when expecting another person's action (e.g., Kilner et al. 2004; Kourtis et al. 2010). However, in our Exp. 3 there was no significant difference between the CNV found in NoGo trials in the joint and individual task settings. Therefore our results cannot distinguish between the CNV portion that is related to the predictable imperative stimulus and the portion related to action prediction.

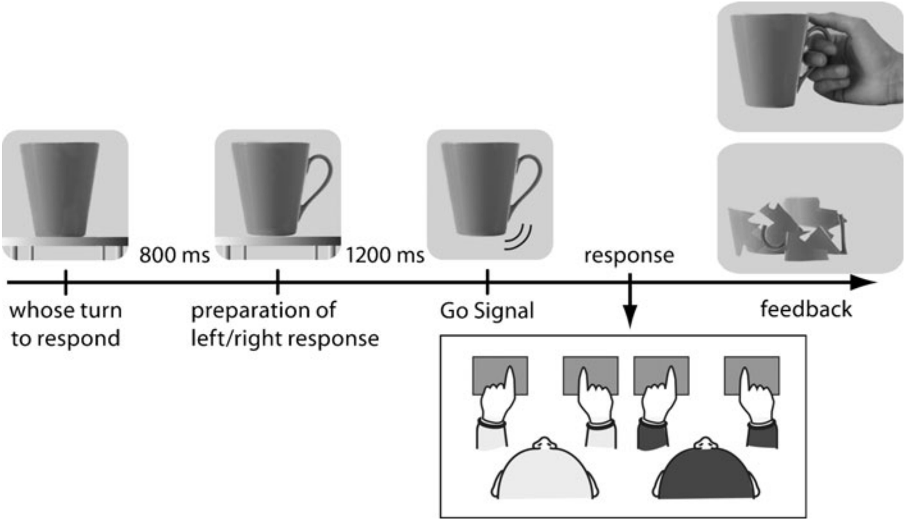

Fig. 4 Schematic of trial events in the cup study. Participants first saw a photograph of the cup without its handle in one of three different colors. Cup color indicated who should respond (the EEG-participant, the co-actor, or neither). The side of the handle indicated which action (pseudo-catching movements with the left vs. right hand) to perform. Participants were supposed to withhold their response until the go-signal. Feedback indicated whether the cup was "caught" in time

3.4 Summary

Section 3 provided an overview of data from different tasks and experiments that investigated joint binary choice go/nogo task performance. Their aim was to elucidate the nature of co-representation in joint task settings. Our initial prediction based on the task co-representation account was that co-representing the other's S-R mappings should lead to vicarious response activation, or response priming, that depends on *which* of the co-actor's stimulus alternatives are presented.

In particular, we expected to find a flanker compatibility effect in the joint condition of Exp. 1 for flanker stimuli assigned to the co-actor. This inter-individual flanker compatibility effect—which can be regarded as a measure of response conflict—should depend on which of the other's responses were primed by the flankers. In Exp. 2a and 2b we investigated joint task switching performance measuring switch costs. Switch costs are known to depend on response activation and response selection on the previous trial. Based on the task co-representation account we assumed that participants would vicariously activate and select their co-actor's response on nogo-trials. Therefore we expected to find switch costs following nogo trials in the joint task setting. Finally, motor-related EEG components on nogo trials of joint task performance were studied for directly investigating vicarious response activation in Exp. 3. According to the task co-representation account, we would have expected to find a nogo-LRP indicating motor preparation processes when it was the coactor's turn.

None of these predictions could be verified. That is, none of these experiments provided evidence in favor of vicarious response activation or for priming of the co-actor's response alternatives during joint binary choice go/nogo task performance.

What are the implications of our findings for co-representation? One possibility is that participants only co-represent their co-actor's S-R mappings when they perform single response go/nogo tasks together, but do not co-represent their partners' more complicated task shares on joint binary choice go/nogo tasks because of limited cognitive resources (e.g., Wickens 2002). According to a representational version of this view, limited cognitive resources imply that participants are not able to co-represent their partners' task share on a representational level in a detailed manner, when this would overall require representing at least four S-R mappings in joint binary choice go/nogo tasks. In contrast, limited resources allow co-representation in joint single response go/nogo tasks because the overall number of to-be-represented S-R mappings in such tasks is only two. In this case, the lack of joint interference effects on joint binary choice go/nogo tasks would be a consequence of not "properly" representing all of the co-actor's S-R mappings on the representational level. An alternative version of this view holds that participants *do* co-represent their partners' choice task shares on a representational level. However, task co-representation might not lead to response-related compatibility effects on the performance level of joint binary choice go/nogo task performance because such effects would require multi-level decisions (the first pertaining to whose turn it is, and only the second pertaining to the specific response required), overtaxing limited cognitive resources during task performance. Regardless of whether limited resources constrain co-representation on the representational or the performance level of joint binary choice go/nogo tasks, the first interpretation thus holds that task co-representation leads to response conflict and hence to joint interference effects in case of joint single response go/nogo tasks, but not in case of joint binary choice go/nogo tasks.

A more radical possibility of interpreting our binary choice task data adopted in this paper is that task co-representation and ensuing response conflict may generally not be the primary source of joint task effects—not even of effects observed in shared single response go/nogo task performance. Instead, effects observed in shared single response tasks might often be due to other contents of co-representation and resulting sources of interference effects than task co-representation and response conflict.

While the null findings reported in this section do not provide information about possible alternative sources of interference in joint task settings, in the next section we report data from a recent study suggesting that actor co-representation and resulting conflict regarding agent identification might be a crucial source of joint interference effects.

4 Actor Co-representation and Agent Identification Conflict in Task Sharing

Philipp and Prinz (2010) targeted the role of conflict pertaining to identifying the responding agent on joint action effects. To this end, they developed a social variant of the Simon task in which participants had to respond to the colour of a target superimposed on the task-irrelevant feature, namely the face of a person. The task-irrelevant faces presented to the participants either depicted the participants themselves (own face), the face of a friend (friend's face), or a non-familiar person (neutral face).

In their first experiment Philipp and Prinz (2010) established a social face-response compatibility effect, that is, a social, non-spatial version of the Simon effect, in individual binary choice task performance. Individual participants responded to the colour of the target diamond by saying one's own name to one colour (e.g., when a white diamond was presented), or by saying the name of the friend when the other colour appeared (e.g., in response to a black diamond). The coloured diamond stimuli randomly appeared on either the participant's own face, on their friend's face (whose name was one of the response alternatives), or on the neutral face. Hence, the task-irrelevant face could be compatible or incompatible with the naming response, or unrelated in case of neutral faces. Results showed a face-name compatibility effect, indicating faster responses when the face on the screen and the naming response were compatible compared to cases when they were incompatible or when neutral pictures were presented. The face-name compatibility effect was present both for responses that required saying one's own name and for responses that required saying the friend's name. These results suggest that the irrelevant face stimulus primed a specific naming response during binary choice task performance, facilitating responding in the compatible condition, but leading to response conflict on incompatible trials.

In a second experiment, Philipp and Prinz (2010) divided the task between two participants in a similar vein as it has been done for the social Simon task (cf. Sebanz et al. 2003), such that each participant performed a single response go/nogo task to only one colour. As usual, participants were responsible for complementary aspects of the task in the joint task setting. The photos of the two participants as well as the photo of a neutral, unknown person served as irrelevant stimuli. In the individual condition, participants performed the same single response go/nogo task alone.

Importantly, Philipp and Prinz (2010) tested three groups of pairs of friends that differed in terms of response requirements. This allowed the authors to (partly) disentangle the role of *response conflict*, on the one hand, and the role of conflict pertaining to the *responding agent*, on the other hand, for interference effects in joint single response go/nogo task performance. Group 1 had to verbally respond by saying their own name in response to "their" color (own name group). Participants in Group 2 pressed a response button (key press group) when their target color appeared. Finally, participants in Group 3 had to verbally respond by saying their friend's name (other name group). Note that in Group 1, compatibility between face identity and agent identity (face-agent compatibility) was confounded with the compatibility between face identity and naming response (face-response compatibility), whereas in Group 3, face-agent compatibility and face-response compatibility diverged. Finally, in Group 2 there was only face-agent compatibility, whereas no compatibility relationship between face identity and (keypress) responses existed.

Across all three groups Philipp and Prinz (2010) found a significant face-agent compatibility effect. That is, participants were always faster to respond when their target appeared on their own face (own-face advantage). Furthermore, this compatibility effect was influenced by social setting: The face-agent compatibility effect was restricted to the joint task setting. No such effect was observed in the individual task setting. These findings suggest a different source for interference in the joint single response go/nogo task than in the individual binary choice task. Specifically, they suggest response conflict was not as important as conflict regarding agent identification. The irrelevant face stimulus presumably primed whose turn it was in the joint task setting, leading to conflict regarding agent identification when the target required a response by the actor who was not primed by the face.

What are the implications of these findings for co-representation? We propose that conflict pertaining to identifying the correct agent (i.e., conflict with respect to determining whose turn it is on a given trial) constitutes a crucial source of interference that can account for many of the joint action effects observed in task sharing experiments. We further suggest that agent identification conflict during task performance may result from actor co-representation on the representational level. According to the *actor co-representation account*, task sharing involves co-representing *that* another actor has to perform the complementary part of a joint task, and *when* it is the other person's turn (i.e., for which stimuli he or she is responsible). Actor co-representation thus changes the representation of an individual single response go/nogo task from "respond to certain stimuli/else withhold response" to "*me* in response to certain stimuli/the *other* in response to certain other stimuli" (in the joint task setting). Note that the actor co-representation account does not assume co-representation of *what* the co-actor is supposed to do under certain stimulus conditions, and hence does not predict response-specific effects on the performance level (i.e., response conflict).

Instead, actor co-representation predicts that agent identification and agent discrimination is more difficult *during* joint as compared to individual task performance. That is, it is more difficult to determine whether it is "my" turn or "the other's" turn (compared to merely deciding whether to respond or to withhold). We suggest that participants meet these increased self-other discrimination demands by relying more strongly on all kinds of cues encountered *during* joint task performance. These cues become associated with "my" viz. the co-actor's turn, even if they are unreliable, and hence may impair performance in some conditions (see below). Examples of such cues pertaining to the tasks and paradigms reviewed above are irrelevant face identity (in the facial version of the Simon task reported in the beginning of this section), finger pointing direction/stimulus position (in the Simon task), letter identity (in the Flanker task), or agent identity in the previous trial (in task switching).

As a consequence, when stimuli and cues associated with the co-actor are presented as irrelevant stimuli in interference tasks, they prime whose turn it is. This leads to interference effects due to agent identification conflict when the co-actor's turn is primed.

In the remainder of this section we will argue that the actor co-representation account is consistent with the majority of the findings reviewed in this paper so far—findings stemming from both, joint single response go/nogo and joint binary choice go/nogo task experiments.

4.1 Re-interpretation of Previous Findings

From our point of view, the actor co-representation account can explain the majority of task sharing results obtained in previous studies. First, it offers an alternative account for joint interference effects observed in single response go/nogo tasks that so far have been exclusively explained by task co-representation and ensuing response conflict. For example, in the joint Simon experiment of Sebanz and colleagues (2003), participants sat side by side with each person operating the key in front of them. Irrelevant spatial information consisted of pictures of left vs. right pointing of fingers, on which the targets (red vs. green rings) were mounted. Actor co-representation can account for the joint Simon effect observed in the Sebanz et al. (2003) study if the actor sitting on the left was (co-)represented as the left (co-)actor, and the actor sitting on the right as the right (co-)actor. In this case, irrelevant finger pointing direction might have primed an agent, leading to agent identification conflict when the finger pointed to one agent (e.g., the left actor), but the other agent (e.g., the right actor) had to respond to the target color. Note that in a standard joint Simon task agent position (left vs. right sitting position) and location of the responses proper (left vs. right key presses) are completely confounded. Therefore it is difficult to distinguish between task co-representation account and actor co-representation. However, recent findings by Liepelt and colleagues (2010) seem to favor the actor co-representation account.

Liepelt et al (2010), using target position (left vs. right side of the screen) instead of pointing direction of fingers as irrelevant spatial information, investigated trial-to-trial sequential modulations of the joint Simon effect in order to get a more complete understanding of its underlying mechanisms (see Liepelt et al. 2010, for details).

Liepelt et al. (2010) replicated Sebanz et al.'s (2003) findings, showing an *overall* Simon effect (on trial N) in the joint but not the individual condition of their single response go/nogo version of the Simon task. In addition, they found that sequential modulations of joint single response go/nogo Simon effect looked (partly) similar to those typically observed when an individual participant performs the whole binary choice Simon task alone (e.g., Stürmer et al. 2002): There was a reliable Simon effect following Simon compatible trials in N-1, and a reversed Simon effect after incompatible trials. Importantly, however, a comparable sequential modulation (i.e., a Simon effect following compatible trials, a reversed Simon effect following incompatible trials) was also observed in the individual condition of the single response go/nogo task. Moreover, the sequential modulation in both, the joint and the individual single response go/nogo conditions was stronger for nogo-go transitions than for go-go transitions, probably reflecting the need to inhibit responses on preceding nogo trials (cf. Neill et al. 1992). Taken together, these results suggest that similar processing mechanisms are involved in the joint and the individual task condition.

The only marked difference between the joint and the individual task setting concerned the size of the Simon effect following compatible trials: In the individual condition, the Simon effect following compatible trials and the reversed Simon effect following incompatible trials were of similar magnitude, so that the overall Simon effect on trial N did not significantly differ from zero.

In contrast, in the joint condition, the Simon effect following compatible trials was larger than the reversed effect following incompatible trials. Consistent with the actor co-representation account, Liepelt and colleagues explained the increase of the joint Simon effect following compatible trials by suggesting that irrelevant stimulus position primed (left vs. right) agents. Specifically, they argued agent-compatible stimulus position encourages the use of stimulus position for determining whose turn it is. A compatible stimulus position (with respect to both actors' positions) is always consistent with the side of the actor who has to respond to the target. Compatible trials following compatible trials keep the assumed link between person and stimulus position intact, thus facilitating responses.

Actor co-representation and agent identification conflict might also be at least partly responsible for the joint single response go/nogo flanker effect observed by Atmaca et al. (2011; see Section 2). The actor co-representation account can explain their findings if one assumes that participants represent some target letters as indicating their own turn, and the complementary letters as signaling the other's turn. Such stimulus-agent associations would lead to agent identification conflict when irrelevant flankers prime the other agent.

As in the joint Simon task with single response responses, the joint *single response* go/nogo flanker effect cannot distinguish between the roles of agent identification conflict and hence actor co-representation, on the one hand, and of response conflict and hence task co-representation, on the other hand. This is because each actor was in charge of only one response, such that the identity of the actors and the identity of the responses overlapped.[4]

However, assuming that single response go/nogo and binary choice go/nogo task performance rely on comparable co-representation processes when it comes to task sharing, the results of our joint binary choice go/nogo flanker experiment (Exp. 1 in Section 3) seem to favor the actor representation account. Our Exp. 1 revealed an own-flanker advantage (i.e., responses were faster when the flankers signaled the same agent as the target than when the target and the flankers were assigned to different agents), that, at least for strongly empathetic participants, was more pronounced in the joint than in the individual condition. At the same time, no spatial or anatomical compatibility effect showed up for flankers assigned to the other person's that would indicate co-activation of the other's *responses* observed in the joint task setting. The task co-representation account has problems explaining these results because the impact of the other persons' flankers should depend on *what* response (left or right) they were supposed to execute. In contrast, the actor co-representation account merely

[4] Note that neutral flankers in the Atmaca et al. (2011) study cannot distinguish between the two accounts either. This is because neutral flankers (that were not assigned to either agent/response) never occurred in the target position, and hence were not associated with "not my turn" or "withhold response". Such a condition would be interesting because the actor co-representation account predicts that flanker stimuli assigned to the other agent should lead to more conflict/interference than neutral flankers (also assigned to nogo/withhold responses) in the joint, but not the individual condition. In contrast, the task co-representation account would not predict differences between joint and individual settings for neutral flanker trials because neutral letters are not assigned to the other's response.

predicts an own-flanker advantage (or an other-flanker disadvantage) in the joint condition.

In a similar vein, the tendency for increased nogo-go slowing in the joint task switching condition of Exp. 2b (see Section 3) might indicate that participants used actor identity on the previous trial as a cue for determining whose turn it is on the current trial. In contrast, the absence of switch costs following nogo trials suggests that participants might *not* have vicariously activated and selected the *response* required by the co-actor.

Taken together, we therefore suggest that actors sharing a task often do not necessarily co-represent *what* the other person is supposed to do under certain stimulus conditions, but only whether and when another actor has to respond. This view is also consistent with recent findings from neuroscience. First, Sebanz et al. (2007) compared brain activation during joint and individual performance of the single response go/nogo Simon task. They found enhanced activation in medial frontal cortex when participants performed their parts in the joint task setting. Medial frontal cortex activation has often been associated with self awareness (see Amodio and Frith 2006, for a review).

Second, and lastly, we recently started to investigate early EEG components indicative of perceptual processing (instead of motor preparation), using a similar task as the one reported in Exp. 3 (see Section 3). Whereas we did not find evidence for vicarious motor preparation in motor-related EEG components in Exp. 3, pilot data for the new experiment suggest that social setting does modulate early perceptual components. This might indicate that actor co-representation on a representational level leads to top-down modulation of perceptual processing related to agent identification during task performance.

5 Discussion

Over the past few years, the cognitive mechanisms that allow humans to achieve desired common goals in joint action have received a great deal of attention. One major line of research on joint action has investigated task sharing. In task sharing, participants take turns in performing complementary parts of a joint task, as in doubles games of table tennis. In this paper we argued that the crucial source of joint interference effects often observed in experimental task sharing studies might not only, or not even primarily, pertain to co-representing another person's task share (i.e., S-R mappings), but instead might concern representing the co-actor as another agent.

Previous studies on task sharing divided standard interference tasks—tasks that usually require binary choice responses by an individual participant—between two participants, such that each participant performed single go/nogo responses to complementary target stimuli. Results from these experiments show that joint single response go/nogo task performance strongly resembles the performance of a single individual carrying out the binary choice task. In contrast, completely different RT patterns were observed when performing one's own share of the task alone in an individual condition of the same single response go/nogo task. The dominant interpretation of such findings so far has been that participants activate one's own as well as the other's representations of S-R mappings as if *performing* the individual binary choice task alone. Therefore the task co-representation account entails co-representation of *what* the co-actor is supposed to do under given stimulus conditions. Task co-representation would allow decoupling action simulation from actual action observation (Sebanz and Knoblich 2009).

Recent finding of our lab are difficult to reconcile with the task co-representation account. These studies aimed to elucidate the nature of co-representation by requesting participants to perform (complementary) joint binary choice go/nogo tasks. Since neither the results from behavioral reaction time experiments, nor results from experiments investigating EEG components related to motor preparation provided support for any kind of *task* co-representation we suggested that *task* co-representation and resulting response conflict may not be the only, or even the primary, source of joint (interference) effects typically observed in joint task settings (even with joint single response go/nogo tasks).

A recent study by Philipp and Prinz (2010) led us to assume that conflicts concerning *agent identification* (i.e., agent or self-other discrimination: determining whether it is “my” turn or “the other’s” turn on a given trial) leads to interference effects observed during joint task performance, instead of, or in addition to, response conflict due to task co-representation. Based on these findings we proposed the *actor* co-representation of what is co-represented on a representational level in joint task settings. According this account, participants in joint task settings do not (co-) represent *how* the co-actor is supposed to respond to certain stimuli. Instead, participants co-represent *that* another person is responsible for the complementary task share, and *when* the other person has to respond (i.e., the stimulus conditions under which it is the co-actor’s turn).

We argued that actor co-representation induces the requirement to distinguish between self and other (self-other discrimination) during joint task *performance* and suggested that participants use all kinds of cues to meet this requirement. Examples of such cues pertaining to the tasks and paradigms reviewed in this paper are (a) irrelevant face identity (in the facial version of the Simon task reported in the beginning of this section), (b) finger pointing direction/stimulus position (in the Simon task), letter identity (in the Flanker task), and (c) agent identity in the previous trial (in task switching).

We showed that actor co-representation and resulting conflicts regarding agent identification during joint task performance offer an alternative explanation for many of the findings previously taken as support for task co-representation and response conflict. Finally, we argued that the actor co-representation account is more eligible to explain the findings obtained with shared binary choice go/nogo tasks than task co-representation.

Of course we are *not* suggesting that task sharing always and only involves actor co-representation, or that agent identification conflict can explain all joint interference effects observed so far (regardless of task or experimental manipulation). On the contrary, there already exist findings that are difficult to reconcile with the actor co-representation account. For example, Welsh (2009) compared individual and joint single response go/nogo Simon performance (with participants sitting alongside each other) when participants operated the key on their side (straight hands control conditions), and when they pressed a key in front of their co-actor (crossed hands conditions). Welsh’s (2009) results indicate that the joint Simon effect with crossed hands depended on the correspondence between stimulus position and location of the response button, not on compatibility between stimulus position and agent (sitting) position (but see Liepelt et al. submitted, for slightly different findings). The actor co-representation account can only accommodate such a finding if it assumes that agent identification is based on “my effector” position, which seems like stretching the account a bit too far.

We do suggest, however, that actor co-representation matters more than previously thought. Future studies need to investigate the impact of actor co-representation on joint effects relative to other forms of co-representation such as *action* co-representation or *task* co-representation (see Section 2) with regard to the specific task used and the kind of experimental manipulation applied. Such studies will need to de-confound stimulus-agent compatibility and stimulus-response compatibility by separating the role of responding agent and the agent’s responses.

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