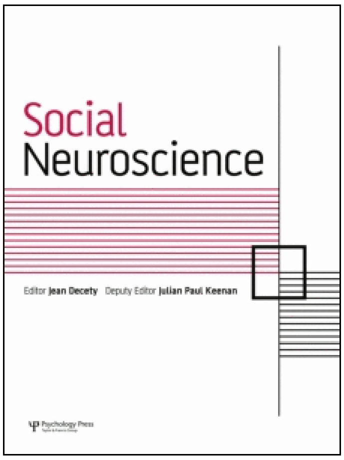

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Action co-representation: The joint SNARC effect

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Action co-representation: The joint SNARC effect

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Traditionally, communication has been defined as the intentional exchange of symbolic information between individuals. In contrast, the mirror system provides a basis for nonsymbolic and nonintentional information exchange between individuals. We believe that understanding the role of the mirror system in joint action has the potential to serve as a bridge between these two domains. The present study investigates one crucial component of joint action: the ability to represent others' potential actions in the same way as one's own in the absence of perceptual evidence. In two experiments a joint spatial numerical association of response codes (SNARC) effect is demonstrated, providing further evidence that individuals form functionally equivalent representations of their own and others' potential actions. It is shown that numerical (symbolic) stimuli that are mapped onto a spatially arranged internal representation (a mental number line) can activate a co-represented action in the same way as spatial stimuli. This generalizes previous results on co-representation. We discuss the role of the mirror system in co-representation as a basis for shared intentionality and communication.

INTRODUCTION

At first glance, the idea that the mirror system (Gallese, Keysers, & Rizzolatti, 2004; Rizzolatti & Craighero, 2004) supports communication seems like a long shot. How can a system that resonates with others' actions (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996), perceptions (Keysers et al., 2004), and emotions (Goldman & Sripada, 2005), support the intentional exchange of symbolic information between a sender and a receiver? Obviously, employing this sort of classical engineering definition of communication creates a seemingly unbridgeable divide between action perception and communication.

However, if one accepts a wider definition of communication that allows for nonsymbolic and nonintentional information exchange, the mirror system presents itself as a potentially powerful device in the service of communication and other forms of social interaction. It can be regarded as a basic link between sender and receiver (Rizzolatti

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& Arbib, 1998) that provides procedural, perceptual, and emotional common ground between individuals (Sebanz, Bekkering, & Knoblich, 2006). If observing you perform an action is similar to performing it myself (e.g., Grezes, Armony, Rowe, & Passingham, 2003), if seeing you being touched is similar to being touched myself (e.g., Keysers et al., 2004), and if perceiving your pain is similar to being in pain myself (e.g., Singer et al., 2004), there is an interpersonal link between us that requires neither symbols nor the intention to communicate.

How can we build on the mirror system to arrive at more sophisticated (symbolic, intentional) forms of communication that entail common, conventionalized knowledge (Clark, 1996) and shared intentionality (Barresi & Moore, 1996)? One possibility is to claim that the mirroring principle is gradually extended from concrete content to more abstract content. For example, Arbib (2005) proposed a progression from the mirroring of instrumental action to hand gestures and, ultimately, to speech (Galantucci, Fowler, & Turvey, 2006; Liberman & Whalen, 2000). While this proposal focuses on changes in content that can be shared interpersonally, it cannot explain the evolution of shared intentionality (Tomasello, Carpenter, Call, Behne, & Moll, 2005). How is it that people can represent a joint task, represent their role in performing a task together, and coordinate their actions to achieve a shared goal? This seems to be a further critical component boosting social interaction and communication (cf. Galantucci, 2005). In fact, there would not be much use for communication but for the need to successfully engage in joint action (Clark, 1996).

We believe that understanding how the mirror system is recruited in the service of joint action may provide a crucial link between implicit, nonsymbolic, and nonintentional information exchange achieved through mirroring, and explicit, symbolic, and intentional information exchange that characterizes discourse (cf. Garrod & Pickering, 2004). The advantage of calling both "communication" is to leave open the possibility that more sophisticated forms of communication still recruit basic systems for social exchange. However, it is equally important to keep in mind that the functionality of the mirror system alone is not sufficient to support joint action (Knoblich & Jordan, 2002; Pacherie & Dokic, 2006). While the mirror system does allow us to understand and predict others' actions and goals, it does not provide the means to jointly attend to the same objects and events (cf. Tomasello, 2000), to effectively perform different parts of a task (Sebanz, Knoblich, & Prinz, 2005; Sebanz et al., 2006), and to coordinate the timing of actions (Knoblich & Jordan, 2003).

As a first step towards understanding how the mirror system supports joint action, we focus on the question of whether and how individuals represent each other's actions when performing different parts of a task together. If the mirror system gets recruited during joint action, coactors should represent their own and others' actions in a functionally equivalent way. Theoretical frameworks extending ideomotor theory (Greenwald, 1970; James, 1890), in particular common coding theory (Hommel et al., 2001; Jeannerod, 1999; Prinz, 1997), have long postulated such a functional equivalence. The common coding theory postulates that the same representations are involved in action production and action observation. The mirror system can be regarded as the neural implementation of this functional principle.

In line with the common coding principle, prior research has shown that observing somebody else concurrently performing the same action as oneself results in facilitation, whereas observing somebody else concurrently performing the opposite action interferes with performing the action (Brass, Bekkering, & Prinz, 2001; Kilner, Paulignan, & Blakemore, 2003; Stuermer, Aschersleben, & Prinz, 2000). Less is known about how actors influence each other's performance when acting in turns, which is prototypical of many types of joint action. When taking turns, one does not perceive competing (or facilitating) information about the other while acting oneself. Rather, influences of the other's actions are expected only if they are part of one's own task representation. In other words, if facilitation or interference occurs in the absence of action observation, one can conclude that coactors represent not only their own, but also the other's potential actions.

In an earlier study (Sebanz, Knoblich and Prinz, 2003), we demonstrated such effects using a variant of a spatial compatibility (Simon) task (e.g., Simon, 1990; Simon, Hinrichs, & Craft, 1970). We found that two participants—each performing half of the task—showed the same compatibility effects as single participants performing the whole task. In the latter condition, single participants responded to the color of a ring that was placed on the index finger of a pointing hand. One color required a left key press and the other color required a right key press. In addition, the hand was pointing either to the right or to the left. Although the pointing direction was irrelevant for the task, participants responded faster with the left key to stimuli pointing left than to stimuli pointing right and vice versa. This spatial compatibility effect occurs because the spatial stimulus feature automatically activates the corresponding action. If the relevant stimulus feature color demands this action, facilitation occurs. If the relevant stimulus feature color demands the opposite action, there is interference between two competing action representations (e.g., Kornblum, Hasbroucq, & Osman, 1990).

In the critical joint condition, pairs of participants performed the task together. Each individual responded to only one of the two colors using only one key. Although participants performed only half of the task, they showed a similar compatibility effect as individuals performing the whole task. In contrast, no compatibility effect was observed when participants performed their half of the task alone (individual condition). This is surprising because—from the point of view of a single participant—the task was exactly the same in the individual and joint conditions. The irrelevant spatial stimulus affected performance in the joint condition but not in the individual condition.

How can this be explained? In the individual condition, only one action was represented, thus no conflict occurred. In the joint condition, the alternative action under the other's control was (co)represented as if it was part of one's own task. Thus, the results were similar to the two-choice condition where single participants performed the whole task. These effects have been replicated in recent studies (Sebanz, Knoblich & Prinz, 2005; Tsai, Kuo, Jing, Hung, & Tzeng, 2006). Importantly, the joint compatibility effect requires only the belief that the other person performs the other part of the task; it does not require observation of the other's task (Tsai, Kuo, Hung, & Tzeng, in press).

Our interpretation of these results is that a task representation that includes the potential actions of others can be as effective in activating action representations as the observation of somebody else's actions. Constraining the mirror system's functionality by a higher-level task representation allows one to keep one's own and the other's part of the task apart without giving up the basic interpersonal link provided through mirroring.

THE PRESENT STUDY

The aim of the present study was to further investigate how coactors form shared representations when performing complementary tasks. We were particularly interested in the question of whether symbolic information can take on the function of spatial or biological cues, such as the pointing hand in the study described above. Proponents of the embodied cognition approach maintain that many abstract symbols still retain aspects of the physical world they represent. One famous example is numbers (cf. Lakoff & Nunez, 2000). Although they are often regarded as highly abstract entities, Dehaene (1997) contends that our internal representation of numbers takes the form of a mental number line with small numbers on the left and larger numbers to the right. This raises the possibility that even the processing of symbolic information makes use of the close perception-links embodied in the mirror system.

The main empirical finding backing the claim that numbers carry spatial content is the so-called 'SNARC' (spatial numerical association of response codes) effect (Dehaene, Bossini, & Giraux, 1993; Fias, 2001; Iversen, Nuerk, & Willmes, 2004; Nuerk, Wood, & Willmes, 2005). In Dehaene and colleagues' (1993) experiments, participants were asked to perform a two-choice task by pressing one key in response to even numbers, and another key in response to odd numbers. The surprising finding was that participants' left responses were faster than right responses for small numbers and vice versa for large numbers. Thus, number magnitude affected response times (RTs), although it was irrelevant for the task. Further experiments (Dehaene et al., 1993) demonstrated that the SNARC effect occurs relative to the given number range. It is independent of handedness, occurs in different modalities, and for different number notations (Fias, 2001; Nuerk et al., 2005; Iversen et al., 2004). Further studies showed that the SNARC effect seems to have its basis in cultural conventions, mainly the writing direction of words (Dehaene et al., 1993).

According to Dehaene (1997), although numbers do not carry spatial information *per se*, the perception of numbers automatically activates a magnitude representation on a mental number line proceeding from the left to the right. Small numbers are associated with left and large numbers are associated with right. The SNARC effect arises because activation of the left part of the number line automatically activates left actions, and activation of the right part of the number line automatically activates right actions (compare Figure 1(a)). Further support for this explanation was provided by Zorzi, Priftis, & Umiltà's (2002) finding that patients with hemispatial neglect, who show systematic biases to the right in line bisection, showed a similar bias towards large numbers when asked to bisect numerical intervals.

In the present study, we used the SNARC paradigm in a similar experimental design as Sebanz and colleagues (2003) to explore whether action corepresentation also occurs when the stimulus is symbolic rather than carrying direct spatial information. In the joint condition, two participants performed complementary actions. Each participant was assigned to one response key (left or right) and was in charge of one mode of parity (odd or even) (see Figure 1(b), left). In the individual condition, participants performed the same go-nogo task alone (see Figure 1(b), right).

We predicted that a SNARC effect would occur in the joint condition, but that no SNARC effect would occur in the individual condition. The rationale is as follows. If each actor in the joint condition represents both her own *and* the coactor's action alternative, the spatial nature of the numerical stimuli should lead to automatic activation of the corresponding actions. Participants should respond faster to small numbers when they are in charge of the left response than when they are in charge of the right response, and vice versa. In the individual condition, no SNARC effect should occur because there is

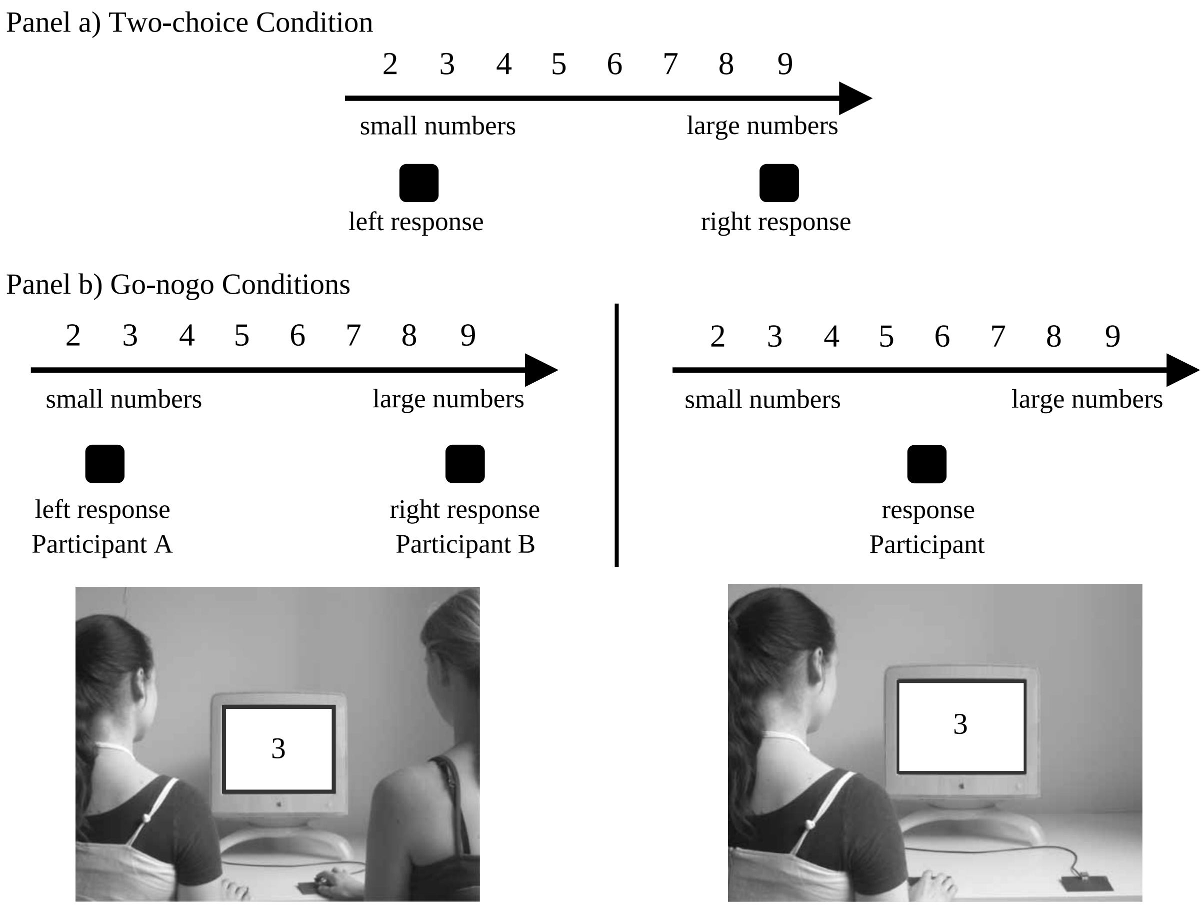

Figure 1. (a) In the two-choice condition, varying degrees of overlap between the spatial number representation and the spatial features of the two actions facilitate left responses to small numbers and right responses to large numbers. (b, left) In the joint condition, the task was distributed between two participants sitting on the left and right. Each participant performed a go-nogo task in response to parity. A SNARC effect in the joint condition would indicate that each participant represents both action alternatives. (b, right) In the individual condition, one participant sitting on the left or right performed the same go-nogo task in response to parity alone. In this condition, no SNARC effect should occur because there is just a single action alternative and thus no conflict.

just a single action alternative at the actor's command and thus no action conflict arises.

EXPERIMENT 1

In this experiment, participants responded to the parity of Arabic digits ranging from 2 to 9. In the joint condition, two participants performed complementary actions, one responding to odd, the other to even (see Figure 2, left). In the individual condition, single participants performed exactly the same task, reacting to only one mode of parity with only one response key (see Figure 2, right). This implies that no response was given on half of the trials (nogo trials). A two-choice condition in which one individual was in charge of both action alternatives, reacting to both even and odd numbers with two different keys, served as a further baseline for the joint condition.

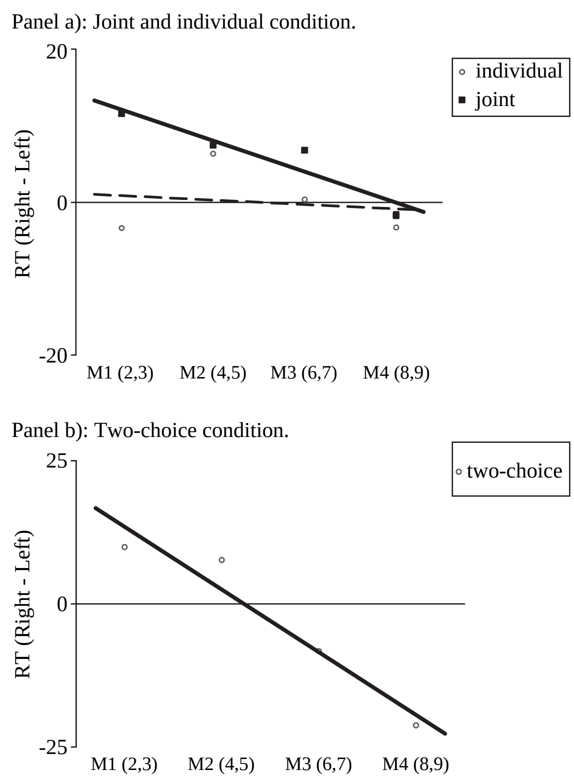

Figure 2. Experiment 1: RT differences of right key minus left key, displayed as function of number magnitude. (a) Joint condition and individual condition (regression line of the joint go-nogo condition: $y = -3.9176x + 15.747$; $R^2 = 0.8633$. Regression line of the individual go-nogo condition: $y = -0.6049x + 1.3982$; $R^2 = 0.0279$). (b) Two-choice condition (regression line: $y = -10.9436x + 24.41$; $R^2 = 0.9334$).

If participants form a representation of each other's actions, a SNARC effect should be observed in the joint condition—resembling performance in a two-choice condition where single participants respond to odd and even numbers—but not in the individual condition.

Method

Of the 56 paid participants (39 female, age range 18–34), 30 performed the individual and joint go-nogo conditions in counterbalanced order. The remaining 26 participants performed only the two-choice task. All participants were right-handed and German native speakers.

Performing exactly the same go-nogo task in the joint and the individual condition, participants gave parity judgments to Arabic digits ranging from 2 to 9, responding with the right index finger (either responding to odd and not even, or vice versa). In the joint condition, two participants were sitting side by side. In the individual condition, there was an empty chair beside the single participant. In the two-choice condition, single participants responded to odd and even numbers with a left and right key press. In each condition, the key assignment varied over the four blocks.

Each trial started with a 500 ms fixation cross (0.57° horizontally and vertically), followed by the number stimulus (0.65° × 1.06°) presented for a maximum of 1500 ms. Once a key was pressed, the stimulus disappeared from the screen and the next trial started after an intertrial interval of 1000 ms. If participants committed an error or took more than 1500 ms to respond, error feedback was provided. Nogo-stimuli in the individual condition were presented for 500 ms, to roughly adjust the presentation time to the joint condition.

In all conditions, participants performed four blocks of 200 trials each. Each block had a different combination of task (respond to odd, respond to even) and response side (left chair, right chair in the individual and joint go-nogo condition, and left and right key in the two-choice condition), and started with eight training trials. Trial order was randomized within blocks.

The experiment was run on an Apple Power PC. The stimulus pictures were presented on an Apple 21 inch monitor (resolution 1024 × 768 pixels). Button presses were recorded with a

PsyScope button box (Cohen, MacWhinney, Flatt, & Provost, 1993).

Results

Results in go-nogo conditions

Incorrect responses did not differ significantly between conditions (joint: 1.4%, individual: 2.1%) and were excluded from further analyses. In order to simplify RT analyses, we averaged over parity, resulting in four levels of number magnitude (2 and 3 constituting Level 1, 4 and 5 constituting Level 2, etc.).

Table 1 gives the mean RTs for each condition. A within-subjects $2 \times 4 \times 2$ analysis of variance (ANOVA) with the factors Condition (joint vs. individual), Magnitude (magnitude level 1–4), and Side (right vs. left key) was computed. There was no significant main effect for Condition ($F(1, 29) = 2.235$, $p = .146$), but there was a significant main effect for Magnitude ($F(3, 87) = 23.876$, $p < .001$). RTs increased over magnitude levels.

Furthermore, there was a significant Magnitude × Side interaction ($F(3, 87) = 3.553$, $p < .05$), and a significant three-way interaction between Condition, Magnitude, and Side ($F(3, 87) = 4.478$, $p < .01$), confirming that there was a significant difference between the joint and the individual conditions regarding the size of the SNARC effect. None of the other interactions was significant.

In a second step, RT differences (right key minus left key) for each level of number magnitude were calculated. The greater the RT difference, the slower the right response compared to the left response to the same number, and vice versa. Thus, a SNARC effect should manifest itself in a negative slope of a regression line, because small numbers should elicit a faster response with the left key, whereas large numbers should lead to faster responses with the right key. Figure 2(a) shows the results. In the joint condition, there was a negative slope that was significantly different from zero ($t(29) = -2.611$, $p < .05$), whereas in the individual condition the slope was not significantly different from zero ($t(29) = -0.515$, $p = .610$). Thus, the SNARC effect was present only in the joint condition.

Results in two-choice condition

There were 3.6% incorrect responses, which were excluded from further analyses. RTs (see Table 1) were entered into a 4×2 within-subjects ANOVA with the factors Magnitude (magnitude levels 1–4) and Side (right vs. left key). There was a significant main effect for Magnitude ($F(3, 75) = 20.565$, $p < .001$) and a significant Magnitude × Side interaction ($F(3, 75) = 13.818$, $p < .001$), confirming that a SNARC effect occurred. There was no significant main effect of Side. Figure 2(b) shows the RT differences between right key and left key. In line with the results of the ANOVA, the regression line had a significant negative slope ($t(25) = -4.458$, $p < .001$).

Discussion

In Experiment 1, the same go-nogo task led to a different RT pattern depending on whether a participant performed the task alone or whether two participants performed complementary tasks. The RT pattern in the joint go-nogo condition more closely resembled the RT pattern in the

TABLE 1

Mean RTs and standard deviations (in parentheses) for Experiments 1 and 2, by condition, magnitude level, and response side

	Magnitude Level 1		*Magnitude Level 2*		*Magnitude Level 3*		*Magnitude Level 4*	
	Left	*Right*	*Left*	*Right*	*Left*	*Right*	*Left*	*Right*
Experiment 1								
Two-Choice	426 (107)	436 (116)	430 (104)	438 (113)	432 (113)	424 (115)	456 (113)	435 (115)
Joint	354 (81)	365 (91)	362 (88)	370 (93)	352 (82)	359 (92)	377 (93)	375 (94)
Individual	347 (77)	343 (73)	351 (76)	357 (80)	346 (75)	346 (76)	363 (77)	359 (76)
Experiment 2								
Joint	513 (117)	522 (121)	559 (126)	570 (135)	592 (144)	585 (146)	623 (146)	611 (147)
Individual	501 (111)	504 (118)	552 (117)	547 (122)	572 (130)	570 (131)	596 (131)	596 (131)

two-choice condition than the RT pattern in the individual go-nogo condition. For the go-nogo task, a SNARC effect was present only in the joint condition (see also Figure 4). These results suggest that participants co-represented each other's actions. Symbolic stimuli can take on the same role as spatial stimuli if they activate representations that carry spatial content.

As can be seen in Figure 2, subjects in the joint condition—and, to a lesser degree, in the individual condition—had an overall tendency to react faster with the left key than with the right key, leading to positive values of RT differences. In contrast, a more symmetrical pattern was observed in the two-choice condition. We do not have a good explanation for the faster left responses in the go-nogo conditions (see discussion of Experiment 2). Importantly, though, this does not affect our interpretation that participants represented the other's action alternative in the joint condition. As predicted, we found a SNARC effect in the joint, but not in the individual condition, the only difference between these two conditions being whether participants performed the task alone or together.

EXPERIMENT 2

The main goal of Experiment 2 was to replicate the joint SNARC effect with a different set of stimuli. We used pictorial representations of numbers formed with the digits of a left and right hand (see bottom of Figure 3). For these stimuli, there are two different types of compatibility. First, there is spatial compatibility: Small numbers involve only digits on the left whereas large numbers increasingly involve digits on the right. Secondly, there is spatial–numerical compatibility, with number magnitude being mapped onto a mental number line proceeding from left to right. Is the activation of the other's action particularly strong when a stimulus refers to the other's action through both a perceptual feature and a spatial feature derived from symbolic information? Although it has been established that the time course of automatic activation is different for perceptual features and spatial features derived from symbolic stimuli (Mapelli et al., 2003), activations from both types of features should converge on the same action. If these two effects add up, the joint compatibility effect should be

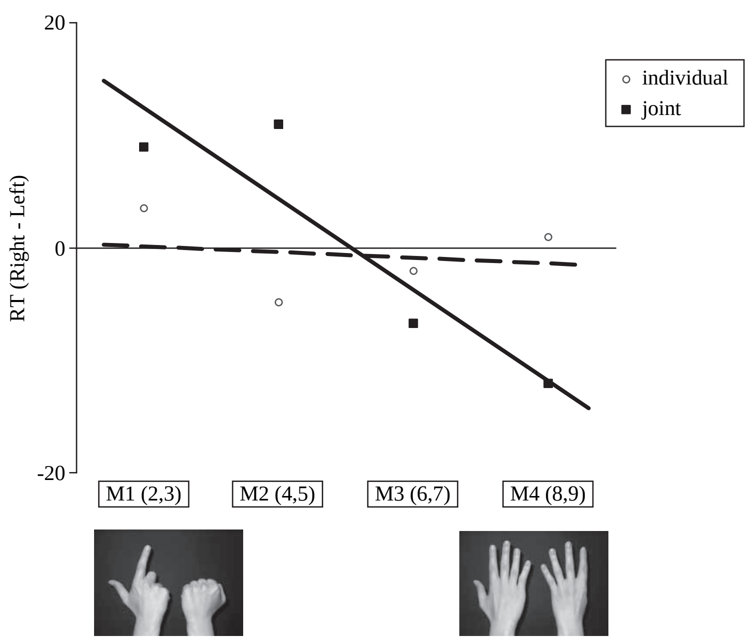

Figure 3. Experiment 2: RT differences of right key minus left key, displayed as a function of number magnitude. Joint condition and individual condition (regression line of the joint condition: $y = -8.0877x + 20.49$; $R^2 = 0.8334$. Regression line of the individual condition: $y = -0.4928x + 0.6131$; $R^2 = 0.0304$). The stimuli were pictures of two hands depicting numbers. The smallest number ("2") was displayed with two fingers extended on the very left. Ascending numbers were formed extending additional fingers from left to right. There was one stimulus picture for each number in the range from 2 to 9 (see numbers "2" and "9" as examples).

even more pronounced in Experiment 2 than in Experiment 1.

Method

Participants

Thirty participants (22 female, age range 20–33) took part in this experiment. All participants were right-handed and German native speakers.

Materials and procedure

The materials and the procedure were the same as in the go-nogo conditions of Experiment 1, except for the stimuli (see bottom of Figure 3). We presented pictures of two hands forming numbers ($16.7^\circ \times 14.04^\circ$ horizontally and vertically). Participants were familiarized with the pictures before the experiment.

Results

Error rates did not differ significantly between the joint (3.8%) and the individual conditions (4.2%). Incorrect responses were excluded from further analyses.

Table 1 gives the mean RTs in each condition. A within-subjects $2 \times 4 \times 2$ ANOVA with the factors Condition (joint vs. individual), Magnitude (magnitude levels 1–4) and Side (right vs. left key) showed no main effect of Condition ($F(1, 29) = 3.723$, $p = .063$), although numerically, RTs in the joint condition tended to be slower. There was a significant main effect for Magnitude ($F(3, 87) = 82.766$, $p < .001$). Furthermore, there was a significant Magnitude × Side interaction ($F(3, 87) = 3.494$, $p < .05$) and a significant three-way interaction between Condition, Magnitude, and Side ($F(3, 87) = 4.767$, $p < .01$), indicating that there was a significant difference between the joint and the individual conditions regarding the size of the compatibility effects. The ANOVA showed no other significant effects.

Figure 3 shows the RT differences of right key minus left key. The negative slope of the regression line significantly differed from zero in the joint condition ($t(29) = -3.476$, $p < .01$), but not in the individual condition ($t(29) = -0.307$, $p = .761$). Thus, there were compatibility effects in the joint condition but not in the individual condition.

COMPARISON BETWEEN EXPERIMENTS

We compared the mean slopes of RT differences of Experiment 2 with those of Experiment 1 (see Figure 4). Whereas the mean slopes were comparable for the individual condition in the two experiments (-0.53 in Experiment 1 and -0.56 in Experiment 2), the mean slope of the joint condition of Experiment 2 (-8.05) was more than twice as large as the mean slope of the joint condition in Experiment 1 (-3.84). Unfortunately, a one-sided *t*-test for independent samples comparing the two slopes of the joint conditions in Experiments 1 and 2 failed to reach significance ($t(58) = 1.536$, $p = .065$).

DISCUSSION

The results of Experiment 2 showed that a joint SNARC effect does not occur only for Arabic digits, but also for frequency depictions using human hands (see, e.g., Nuerk et al. (2005) for similar results with dice patterns). The mean slope of the regression line in the joint condition of Experiment 2 was more than twice as large as the mean slope in the joint condition in Experiment 1 (see Figure 4), supporting the assumption that there were spatial compatibility effects in addition to spatial–numerical compatibility effects. Unfortunately, a statistical comparison between the slopes obtained in the joint conditions of Experiments 1 and 2 failed to reach significance.

However, in support of the additivity assumption, a later follow-up experiment did not show a significant joint compatibility effect for stimuli of

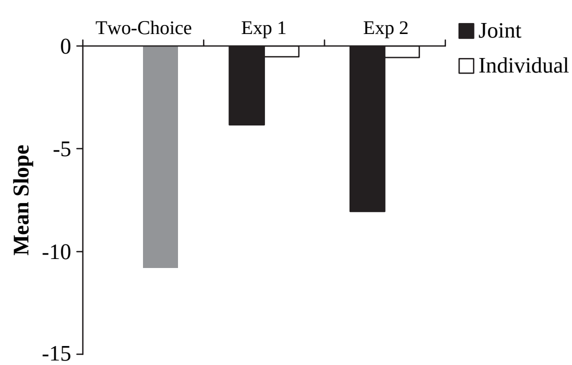

Figure 4. Mean slopes of RT differences of the two-choice condition and of the joint and the individual conditions in Experiments 1 and 2.

human hands where magnitude increased from right to left. These stimuli create a conflict between numerical–spatial compatibility and spatial compatibility. The lack of joint compatibility effects in the follow-up experiment suggests that spatial compatibility and numerical–spatial compatibility cancelled each other out. Thus, the numerically larger negative slope in Experiment 2 likely reflects the combination of two different compatibility effects.

Unlike in Experiment 1, the SNARC effect in the joint condition appeared to be quite symmetrical, indicating that an overt spatial component is possibly necessary for a symmetrical joint SNARC effect to occur. RTs in the joint and the individual conditions in Experiment 2 tended to be about 200 ms slower than in Experiment 1. This could have been due to the inherently more complex nature of the pictures depicting hands compared to the single numbers presented in Experiment 1. Given that previous research has clearly shown that the SNARC effect does not vary as a function of RT (Mapelli, Rusconi, & Umiltà, 2003), we consider it unlikely that this increase alone could explain the increase of the joint SNARC effect compared to Experiment 1.

GENERAL DISCUSSION

The present results suggest that action co-representation is a general phenomenon that occurs whenever complementary actions are distributed across different people. The joint SNARC effect obtained in the present experiments can be explained by the assumption that when two people make complementary parity judgments, each individual forms a representation of both action alternatives. The numerical stimuli automatically activated a representation of the corresponding action, regardless of whether it was at one's own or the other's command. On compatible trials, stimuli activated the action to be performed, facilitating action execution; whereas on incompatible trials, stimuli activated a representation of the action not to be performed, leading to an action selection conflict that slowed down the responses. This was not true for the individual condition, because only one action alternative was represented. Furthermore, the larger co-representation effects in Experiments 2 suggest that perceptual spatial features and spatial features derived from symbolic stimuli can concurrently activate a co-represented action.

More generally, effects of co-representation suggest that when people perform different parts of a task they tend to represent the whole task at hand rather than just their own part in the task. Importantly, action alternatives at another's disposal appear to be represented in a similar way to action alternatives at one's own disposal. Although we have not obtained direct evidence for the neural mechanisms underlying co-representation so far (but see Sebanz, Rebbechi, Knoblich, Prinz, & Frith, 2007), it is likely that the mirror system enables us to represent our own and others' actions in a functionally equivalent way when performing complementary parts of a task together. Note that this does not imply that there is no difference between performing the whole task alone (two-choice condition) and performing the task together with another person. Obviously, response selection conflicts are stronger when both action alternatives really are at one's own disposal (Burle, Possami, Vidal, Bonnet, & Hasbroucq, 2002). However, a conflict also occurs when another action alternative is kept in a state of readiness, be it because one occasionally happens to be in charge of it (Hommel, 1996), or because one knows someone else to be in charge of it, as was the case in our experiments.

The results suggest that the mirror system is not engaged only in action observation, because concurrent perceptual input about a coactor's actions is not required (Kilner, Vargas, Duval, Blakemore, & Sirigu, 2004; Sebanz et al., 2003). Rather, any stimulus that refers to a coactor's action might have the potential to activate action representations in the mirror system. If this assumption is valid, the mirror system could generally support joint task performance because it provides a platform for integrating action alternatives at one's own and others' command (Knoblich & Jordan, 2002).

However, the functionality of the mirror system alone is not sufficient to support joint action. In the present experiments, participants came to represent the other's action alternative in the joint condition because they knew from the start how the respective parts of the whole task would be distributed between the two coactors. In other words, they might have formed a task representation that entailed stimuli they did not need to react to and an action alternative not at their own command (Sebanz et al., 2005; Atmaca, Sebanz, & Knoblich, 2008). Without such a task representation, no mirror system activation can be expected. The claim that higher level planning structures can provide a context within which the mirror system operates (Erlhagen, Mukovskiy, & Bicho, 2006) has the potential to explain how the mirror system supports different (non-imitative) forms of joint action. On one hand, higher-level task representations would ensure flexible links between environmental and social conditions and suitable actions. On the other hand, the task representations would include action representations that are functionally equivalent for self and other and thus ensure that one can interpret (Rizzolatti & Craighero, 2004) and predict (Decety & Grezes, 2006; Wilson & Knoblich, 2005) others' actions even when a joint task requires complementary actions. Clearly, further research is needed to establish how the interplay between higher level task representations and the mirror system enables joint action. We believe that this interplay could be the key to understanding the emergence of shared intentionality that is critical not only for joint action but also for its symbolic counterpart, communication.

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