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BRIEF REPORT

Joint response–effect compatibility

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Abstract When performing jointly on a task, human agents are assumed to represent their coactor's share of this task, and research in various joint action paradigms has focused on representing the coactor's stimulus–response assignments. Here we show that the response–effect (R–E) contingencies exploited by a coactor also affect performance, and thus might be represented as if they were used by oneself. Participants performed an R–E compatibility task, with keypresses producing spatially compatible or incompatible action effects. We did not observe any R–E compatibility effects when the task was performed in isolation (individual go–no-go). By contrast, small but reliable R–E compatibility effects emerged when the same task was performed in a joint setting. These results indicate that the knowledge of a coactor's R–E contingencies can influence whether self-produced action effects are used for one's own motor control.

Keywords Joint action · Motor control · Action effects · R–E compatibility

Research on human motor control has recently moved toward investigating human actions in their social context (Becchio, Sartori, & Castiello, 2010; Knoblich & Sebanz, 2008; Marsh, Richardson, & Schmidt, 2009). Accordingly, several paradigms that have typically relied on single individuals have been adapted to the social context by having multiple participants work jointly on a task.

The most prominent example of this line of research is the Simon effect, which indicates that response-irrelevant features of a target stimulus automatically tend to activate actions with compatible features (Simon, 1969). In the corresponding joint Simon setting (Sebanz, Knoblich, & Prinz, 2003), the stimulus–response mapping of a simple two-choice task is distributed among two participants, who operate one response button each. In other words, each participant works on half of the task and does not have to respond in the other half of the trials. If such a go–no-go task is performed in isolation (i.e., without a coactor), compatibility effects are usually absent or significantly reduced. If participants work jointly on the same go–no-go task, however, compatibility effects resurface (i.e., joint Simon: Kiernan, Ray, & Welsh, 2012; Sebanz et al., 2003; joint SNARC: Atmaca, Sebanz, Prinz, & Knoblich, 2008; joint flanker: Atmaca, Sebanz, & Knoblich, 2011). Because performance in these tasks closely mirrors the picture that emerges if a single participant is responsible for the entire task, the results from joint settings have been considered to provide evidence for the idea that human agents tend to co-represent others' actions or tasks (see Knoblich, Butterfill, & Sebanz, 2011, for a review).

This interpretation is further reinforced by findings from numerous other experimental paradigms that have been adopted in the joint action framework, ranging from perception (Richardson et al., 2012) and attention (Böckler, Knoblich, & Sebanz, 2012; Welsh et al., 2005, 2007), to working memory (He, Lever, & Humphreys, 2011) and music production (Novembre, Ticini, Schütz-Bosbach, & Keller, 2012).

Taken together, these findings suggest that human agents indeed represent their coactor's task, which is assumed to facilitate action prediction and coordination with others. Yet, they do not address directly which aspects of this task are

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represented. In a Simon task, for instance, stimulus locations prime spatially corresponding responses, which creates benefits when a compatible response should actually be carried out. The same priming incurs costs when a spatially incompatible response is required, because the primed response must be suppressed. Benefits in a joint Simon task can be explained by assuming that the positions of the stimulus and the own response are spatially coded (as left or right) relative of the action of the coactor, such that a spatially corresponding stimulus primes the single own response. To explain costs, additional assumptions are needed—namely, that the response alternative of the coactor is represented and suppressed like an own response alternative. The most parsimonious explanation of the joint Simon effect is the subject of some debate, but it seems that a spatial representation of the coactors response, which serves as a reference point for the spatial coding of stimulus positions and the own response, is crucial, as it reintroduces a dimensional overlap of stimulus–response features—a necessary condition for Simon effects to emerge (Dolk, Hommel, Prinz, & Liepelt, 2013; cf. Kornblum, Hasbroucq, & Osman, 1990; Kornblum & Lee, 1995).

However, priming of spatially (or otherwise) corresponding motor actions can originate from events other than stimuli. It can result from imagined (Tlauka & McKenna, 1998) or at least predictable future events that are not even perceptible at the moment that the action is carried out. In the present study, we explored the role of priming by predictable action consequences, hence *action effects*.

Cumulative evidence indicates that human agents code their actions in terms of action effects—that is, the sensory consequences of these actions (e.g., Hommel, 1993; Kunde, 2001; see also Hommel, Müsseler, Aschersleben, & Prinz, 2001), including changes in the behavior of other agents (Pfister, Dignath, Hommel, & Kunde, 2013). On the basis of the ideomotor-inspired framework of common coding (Hommel et al., 2001; Prinz, 1990), what holds true for coding one's own actions seems to apply to the coding of other-generated actions, too (Dolk et al., 2013a; Kiernan et al., 2012; Sebanz et al., 2003). Furthermore, anticipating potential action effects is seen as a central mechanism in human action control. In other words, effect representations seem to be linked directly to the motor system (Hommel, 2009; Kunde, 2001).

A suitable tool for investigating the impact of such effect anticipations is the *response–effect (R–E) compatibility* paradigm (Kunde, 2001, 2003; Pfister & Kunde, 2013). In a typical setup for studying spatial R–E compatibility, responses with a left or right response key trigger action effects to the left or to the right of the participants. In R–E compatible trials, the response location and the effect location match (e.g., right response ▸ right effect), whereas in R–E incompatible trials, the response location and the effect location do not match (e.g., right response ▸ left effect). Even though action effects only occur after action execution, responses tend to be faster in the compatible than in the incompatible condition (cf. also Gaschler & Nattkemper, 2012; Pfister, Kiesel, & Melcher, 2010; Shin & Proctor, 2012).

It should be noted, however, that anticipating sensory events in the agent's environment seems to be a rather effortful process that depends on several preconditions. For instance, using trial-to-trial-varying R–E relations, Ansorge (2002) observed reliable R–E effects only if participants were explicitly instructed to produce the effects, but not if the effects simply appeared as a task-irrelevant by-product of own actions. Similarly, Janczyk, Pfister, Crognale, and Kunde (2012) found a direct impact of effect anticipations only if the corresponding effects were salient and task-relevant at the same time. On the basis of research on various joint action paradigms, we expected the social setting to boost effect anticipations if a coactor was equally able to exploit R–E contingencies. Direct evidence for this hypothesis comes from a recent study that introduced action effects in the joint Simon paradigm (Kiernan et al., 2012). In this study, the joint Simon effect was reversed when responses switched on a light at the opposite location—clearly suggesting that action effects changed action coding in this social setting.

To summarize, studies in the spatial R–E compatibility design basically draw on the same logic as studies on the Simon effect, but they focus on events that are anticipated (response effects) rather than perceived (response-affording stimuli). To the extent that in the joint Simon setting features of a coactor's stimulus–response relations impact one's own behavior, it is conceivable that features of the R–E relations of a coactor will do so in a joint R–E setting. Following the rationale of previous joint action paradigms, this was tested in the present study by having participants work on both an individual and a joint variant of a go–no-go task. More specifically, we expected a negligible or absent R–E compatibility effect for the individual go–no-go task, whereas we expected stronger R–E compatibility effects in the joint setting (as is usually observed for the Simon effect; Sebanz et al., 2003).

Method

Participants

A total of 32 undergraduate students (22 female, 10 male; mean age = 24.4 years, *SD* = 2.7) were paid for participation. All participants were right-handed and were naive with regard to the hypotheses of the experiment. The data of one pair of participants were not included in the analyses due to an error in the experimental procedure. Exploratory analyses ensured that including the available data of these participants did not change the pattern of results.

Setup and apparatus

Upon arrival at the laboratory, participants were informed that they would perform the same task in two different conditions; that is, they would act alone in one condition (individual go–no-go) and together with the other person in the other condition (joint go–no-go).

In the *joint condition*, both participants were seated next to each other in a sound-attenuated, dimly lit room. They operated a response button with their right index finger (25 cm in front and 25 cm from the midline of a 17-in. computer monitor), and they were asked to place their left hand underneath the table on their left thigh. The monitor showed a stimulus array (34.5 cm × 6.5 cm, horizontally × vertically) featuring three stimuli: a wagon in the center (4.5 cm × 2.2 cm) that was flanked by magnets (5.5 cm × 6.5 cm) to the left and right (Fig. 1). The target stimuli were the letters H and X (0.8 cm × 0.9 cm) that were superimposed on the wagon, and letter–response assignments were counterbalanced across participant pairs. Participants received written instructions and were encouraged to respond as quickly and accurately as possible to their assigned stimulus.

Crucially, the participants were informed that each response would activate a magnet. Activating a magnet instantly changed its appearance, and the wagon started moving toward this magnet (see the effect display in Fig. 1). In separate blocks, the response keys were "connected" either to the magnet on the same side (R–E compatible trials) or to the magnet on the opposite side (R–E incompatible trials). The order of the two R–E mappings was counterbalanced across participant pairs.

In the *individual condition*, everything was held constant (assigned stimulus and response side), except that the left or right chair remained empty (counterbalanced across participants). Half of the participants started with the joint followed by the individual condition, whereas the other half performed the conditions in the reverse order.

Procedure

There were three blocks, one training block of ten trials and two experimental blocks of 80 trials, for each condition (individual vs. joint) and R–E mapping (compatible vs. incompatible). Blocks were separated by short breaks to allow the participants to maintain vigilance throughout the experiment.

Each trial began with the presentation of the stimulus array for 500 ms. After 500 ms, the target stimulus (H or X) was presented until either a response was given or 1,000 ms had passed. Correct responses switched on a magnet (depending on the current R–E mapping) and caused the wagon to move toward this magnet (for 1,000 ms). The magnet switched off automatically when the wagon had traveled halfway to it, causing the wagon to reverse its direction and roll back into the central position for another 1,000 ms. Incorrect responses aborted the trial immediately, and error feedback was displayed for 1,000 ms. In either case, trials were separated by an intertrial interval (ITI) of 1,000 ms.

Results

Response times (RTs)

We excluded trials with errors (0.7%) from the analyses and corrected for outliers by discarding trials in which the RT deviated from the corresponding cell mean by more than 2.5 standard deviations (2.4%), calculated separately for each participant and design cell. Mean RTs were then subjected to a 2 × 2 repeated measures analysis of variance (ANOVA) with the factors Condition (individual vs. joint) and R–E Mapping (compatible vs. incompatible).

Figure 2 shows the corresponding descriptive statistics for the RT analysis. The ANOVA indicated that participants responded significantly faster in the joint condition (323 ms) than in the individual condition (343 ms), $F(1, 29) = 13.61$, $p < .001$, $\eta_p^2 = .32$. The main effect of compatibility did not approach significance, $F < 1$, but a significant interaction indicated that the R–E compatibility effects differed between conditions, $F(1, 29) = 5.64$, $p = .024$, $\eta_p^2 = .16$.

Considered separately, the difference between compatible and incompatible trials was significant for the joint condition (320 vs. 326 ms), $t(29) = 2.90$, $p = .007$, $d = 0.53$, whereas the reversed compatibility effect in the individual condition was not (345 vs. 340 ms), $t(29) = 1.23$, $p = .227$, $d = 0.23$.[1] Finally, we performed an additional 2 × 2 × 2 split-plot ANOVA with Order of R–E Mappings as between-subjects factor, and the corresponding three-way interaction was not reliable, $F < 1$.

To further ensure that the absent effect for the individual condition was not due to overall differences in RT levels, we reanalyzed the data but included only similar ranges of RTs in the analysis. Accordingly, we repeated the ANOVA on RTs but used only the 1st–3rd quintiles of the RT distribution for

[1] It should be noted that the individual condition did not feature any wagon movement in no-go trials, whereas the joint condition did. The absent effect in the individual condition could thus be explained by assuming reduced saliency of the action effects in this condition. To rule out such an alternative explanation, we tested 16 additional participants who completed the individual condition only. This time, however, correctly withholding a response in no-go trials also caused the wagon to move, as it would have done in the joint condition. This control condition fully replicated the absent effect of the original setup (391 vs. 390 ms), $t(15) = 0.30$, $p = .770$, $d = 0.07$. We thank an anonymous reviewer for drawing our attention to this point.

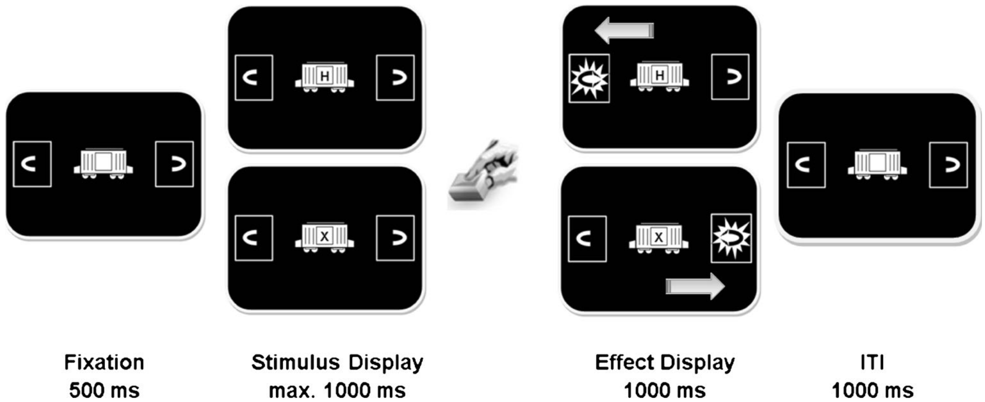

Fig. 1 Trial procedure. Each trial started with the presentation of the stimulus array, in which the target stimulus (H vs. X) appeared after 500 ms. In the joint condition, this target prompted either the left or the right participant to respond. In the individual condition, each participant responded to one letter, whereas the other letter indicated no-go trials. Correct responses activated the magnet on the left or the right (depending on the current R–E mapping), and the wagon started moving toward this magnet. No-go trials in the individual condition featured the stimulus array for 1,000 ms instead of the moving wagon

the individual condition (310 vs. 307 ms) and the 2nd–4th quintiles for the joint condition (313 vs. 320 ms, for compatible and incompatible trials, respectively). This procedure parallelized the two conditions in terms of mean RTs, and the main effect of condition was no longer significant, $F(1, 29) = 2.53$, $p = .123$, $\eta_p^2 = .08$. By contrast, the interaction of condition and R–E mapping was still significant, $F(1, 29) = 5.02$, $p = .026$, $\eta_p^2 = .16$, ruling out alternative explanations in terms of overall RT level.

Error rates

A 2 × 2 repeated measures ANOVA similar to that for RTs showed the main effect of condition to be significant, $F(1, 29) = 11.45$, $p = .002$, $\eta_p^2 = .28$, with a lower error rate in the individual condition (compatible, 0.5%; incompatible, 0.2%) than in the joint condition (1.0% for both compatibility conditions). Neither the main effect of compatibility nor the interaction approached significance (Fs < 1).

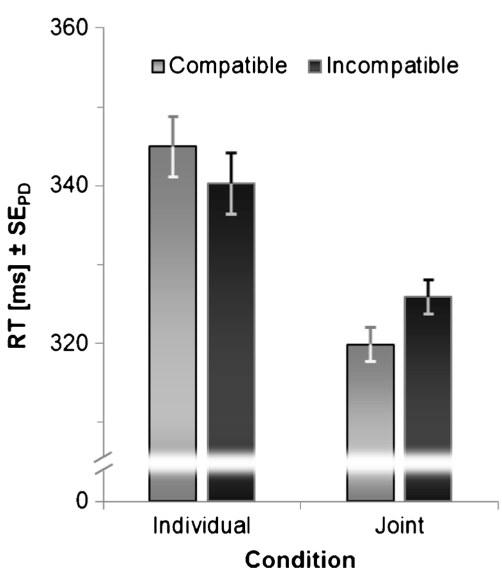

Fig. 2 Mean response times (RTs) as a function of condition (individual vs. joint) and R–E mapping (compatible vs. incompatible). Error bars represent standard errors of paired difference scores, calculated separately for each condition (SE_{PD}; Pfister & Janczyk, 2013)

Discussion

In the present study, we explored the impact of effect anticipations in joint action. To investigate the representation of action effects and its impact on an individuals' own action control, we employed an R–E compatibility paradigm and distributed two response alternatives among two participants working jointly on the task (joint condition). This condition was contrasted with an individual condition, in which the participants performed the same go–no-go task without coactor.

The results were clear cut: In the joint condition, performance was affected by the current R–E mapping; that is, responses that would produce compatible effects were initiated more quickly than responses that would produce incompatible effects. In the individual condition, by contrast, the R–E mapping did not have any effect. This pattern of results is in line with other joint compatibility effects, as is the relatively small effect size (Atmaca et al., 2011, 2008; Dolk et al., 2011; Dolk et al., 2013; Kiernan et al., 2012; Liepelt, Wenke, Fischer, & Prinz, 2011; Sebanz et al., 2003).

Interestingly, we also observed faster responses in the joint condition than in the individual condition. Tentatively, this difference might be attributed to different speed–accuracy trade-offs in both conditions, possibly accentuated by social facilitation in the joint condition (Atmaca et al., 2011; Liepelt et al., 2011). This assumption appears to be likely to account for the present observation, since faster responding in the presence of an active coactor has been shown repeatedly in other joint action paradigms (Atmaca et al., 2011; Kiernan et al., 2012; Liepelt et al., 2011). However, the question of whether such socially induced boosting in RTs solely reflects a speed–accuracy trade-off or whether it can be considered as reflecting a consequence of working together on a task more generally clearly goes beyond the scope of the present study and therefore awaits further research.

Thus, the spatial correspondence between an action and its predictable effects impacts performance when a coactor also exploits R–E contingencies. This basically mirrors observations from the joint Simon task regarding the impact of spatial correspondence between stimuli and responses, and thus invites similar interpretations.

As is the case with the joint Simon task, it remains to be clarified whether the social setting is indeed a necessary prerequisite for the joint R–E compatibility effect (as suggested by Kiernan et al., 2012). The social Simon effect, for instance, seems to be largely driven by the salience of the shared spatial dimension of the stimuli and responses (Dittrich, Dolk, Rothe-Wulf, Klauer, & Prinz, 2013; Dittrich, Rothe, & Klauer, 2012; Dolk et al., 2011, 2013, 2013b; Guagnano, Rusconia, & Umiltà, 2010; Humphreys & Bedford, 2011; see also Ansorge & Wühr, 2004). A similar approach might also be able to explain the joint R–E compatibility effect studied in the present experiment (cf. Pfister & Kunde, 2013). More precisely, the coactor (or any other salient point of reference) might increase the task relevance of the spatial left–right dimension of the actions, and possibly induce referential coding with regard to this point of reference to discriminate the representation of action alternatives (Dolk et al., 2013). Consequently, increasing the task relevance of such spatial action features might also increase the salience of spatial action effects, thus reintroducing a spatial R–E feature overlap that, in turn, would exert a stronger impact on action control (for related accounts, see Janczyk, Pfister, Crognale, & Kunde, 2012; Janczyk, Pfister, & Kunde, 2012). By contrast, recent research on the acquisition of R–E associations suggests that such associations can be picked up by observational learning (Paulus, van Dam, Hunnius, Lindemann, & Bekkering, 2011) and instruction (Pfister, Pfeuffer, & Kunde, 2013). These findings clearly can only be explained by assuming that the R–E contingencies of others are represented much like one's own.

Finally, it should be noted that the present setting is perhaps more "social" than the joint Simon task is, or at least has the potential to be so. The setting can be construed as one in which actors do something for themselves (moving the wagon toward them) or to the coactor (moving the wagon toward him or her). In a competitive situation such as the present one, in which coactors tend to mutually compare their performance, it is perhaps generally harder to pass a neutral (or perhaps moderately positive) object to a competitor, rather than to oneself, irrespective of spatial correspondence relations. This could be tested by manipulating the cooperative versus competitive nature of the task setting and the valence of the transferred objects. This question clearly awaits further research, and the present design offers a potentially useful tool to study such mechanisms.

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