Psychological Research
DOI 10.1007/s00426-015-0664-y

ORIGINAL ARTICLE

Do you really represent my task? Sequential adaptation effects to unexpected events support referential coding for the joint Simon effect

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Received: 28 April 2014 / Accepted: 24 March 2015

Abstract Recent findings suggest that a Simon effect (SE) can be induced in Individual go/nogo tasks when responding next to an event-producing object salient enough to provide a reference for the spatial coding of one's own action. However, there is skepticism against referential coding for the joint Simon effect (JSE) by proponents of task co-representation. In the present study, we tested assumptions of task co-representation and referential coding by introducing unexpected double response events in a joint go/nogo and a joint independent go/nogo task. In Experiment 1b, we tested if task representations are functionally similar in joint and standard Simon tasks. In Experiment 2, we tested sequential updating of task co-representation after unexpected single response events in the joint independent go/nogo task. Results showed increased JSEs following unexpected events in the joint go/nogo and joint independent go/nogo task (Experiment 1a). While the former finding is in line with the assumptions made by both accounts (task co-representation and referential coding), the latter finding supports referential coding. In contrast to Experiment 1a, we found a decreased SE after unexpected events in the standard Simon task (Experiment 1b), providing evidence against the functional equivalence assumption between joint and two-choice Simon tasks of the task co-representation account. Finally, we found an increased JSE also following unexpected single response events (Experiment 2), ruling out that the findings of the joint independent go/nogo task in Experiment 1a were due to a re-conceptualization of the task situation. In conclusion, our findings support referential coding also for the joint Simon effect.

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Introduction

As humans, we are often engaged in task situations where we share a task with other individuals. We do this for the joy of playing a game together such as soccer or table tennis, but also when we have to coordinate our actions with those of others to reach goals that we are not able to achieve alone (e.g., carrying a heavy piece of furniture). In the last decade, a growing number of studies have been conducted investigating the requirements and mechanisms of joint action that are essential to achieve fluent and frictionless joint-task performance.

One of the most prominent paradigms to investigate the cognitive mechanisms underlying joint action is the joint (go/nogo) Simon task. The joint go/nogo task was developed by Sebanz, Knoblich and Prinz (2003) and can be considered as a joint version of the standard (two-choice) Simon task (Simon & Rudell, 1967). In the standard Simon task an individual participant carries out a two-choice reaction task by responding with a left key press to one stimulus (e.g., square) and with a right key press to another stimulus (e.g., diamond). In each trial, one of the two stimuli is randomly presented on either the left or the right side of the monitor. Many studies have shown that although stimulus location is task irrelevant it nevertheless has a strong effect on task processing (e.g., Lu & Proctor, 1995; Simon, 1990). Responses are typically faster when stimulus and response location are compatible (i.e., stimulus

Published online: 02 April 2015

assigned to a left key response appears on the left side of the screen) than when they are incompatible (i.e., stimulus assigned to a left key response appears on the right side of the screen). This compatibility effect is called the Simon effect (SE). The most widely accepted explanation supposes that this effect is caused by an overlap of the irrelevant spatial stimulus dimension and the spatially defined response dimension (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kornblum, Hasbroucq, & Osman, 1990; Nicoletti & Umiltà, 1989). That is, the irrelevant spatial feature of the stimulus automatically activates the corresponding response, which facilitates response selection when the relevant stimulus feature requires this response, but interferes, when the relevant stimulus feature requires the alternative response leading to response selection conflict and hence delays responses (Hommel, 2011; De Jong, Liang, & Lauber, 1994).

In the joint go/nogo task, couples of participants share a standard (two-choice) Simon task. One actor performs one half of the task (e.g., respond to square) and the other actor performs the complementary half of the task (e.g., respond to diamond), which renders the task a simple go/nogo task for both actors. In their seminal work, Sebanz et al. (2003) have shown that the typical compatibility effect found in standard Simon tasks does not occur when an actor individually performs only half of the standard Simon task alone (i.e., Individual go/nogo task) but re-appears when another participant sitting next to the actor responds to the complementary stimulus (joint go/nogo task). The (typical) absence of the compatibility effect when a participant performs a go/nogo task individually has been explained by the assumption that participants do not spatially represent their own response (rather, participants may represent whether to respond or to withhold response) as the alternative response location is removed, which eliminates the response selection conflict (Hommel, 1996; Shiu & Kornblum, 1999; Ansorge & Wühr, 2004). Sebanz and colleagues logically explained the re-appearance of the joint Simon effect (JSE) in the joint go/nogo task analogously to the standard (two-choice) SE through a dedicatedly social perception–action mechanism. That is, although the joint task does not require taking the co-actor's action or task into account, both actors not only represent their own task rule including their stimulus–response (S-R) mappings, but also co-represent the other's task shares in a functionally similar way as one's own (i.e., actors represent to which stimulus the co-actor has to respond and what kind of action the co-actor has to perform to this stimulus according to a given task rule). Co-representing the other's task rules leads to an activation of the other's action when the respective stimulus is presented in a joint go/nogo task (task co-representation). When the relevant stimulus feature activates a different action alternative than the irrelevant stimulus feature, a response selection conflict arises, which slows down responses on incompatible trials—as in the standard Simon task. As the joint go/nogo task is a turn-taking paradigm, so that the responses of the partner are not perceivable when the actor responds, the JSE is assumed to evolve from the internal activation of the co-actor's response with reference to the alternative stimulus (Sebanz, Knoblich, & Prinz, 2005; Tsai, Kuo, Jing, Hung, & Tzeng, 2006).

This action or task co-representation view of the JSE is also supported by findings showing that the JSE can be introduced across two persons even when they are placed in two separate rooms (Tsai, Kuo, Hung, & Tzeng, 2008; but see Welsh, Higgins, Ray, & Weeks, 2007). Further studies have shown that the commonality of the task set implemented by task instructions (i.e., interdependency/independency) and the relationship between both actors (e.g., cooperative/competitive, positive/negative) can modulate the size of the JSE (Hommel, Colzato, & van den Wildenberg, 2009; Iani, Anelli, Nicoletti, Arcuri, & Rubichi, 2011; Ruys, & Aarts, 2010). For example, Ruys and Aarts investigated whether the independency and interdependency of both actors' actions affect the JSE. They found the size of the JSE to be significantly decreased in the independent condition as compared to interdependent conditions. They concluded that a co-actor's actions are integrated more strongly into one's action system especially when interdependency is present during joint-task performance. So far, the JSE has been replicated in many studies (e.g., Dittrich, Dolk, Rothe-Wulf, Klauer, & Prinz, 2013; Dittrich, Rothe, & Klauer, 2012; Kiernan, Ray, & Welsh, 2012; Liepelt et al., 2012a; Tsai et al., 2006; for an overview see Wenke et al., 2011). Further, studies on joint action phenomena provided evidence for a joint Flanker effect (Atmaca, Sebanz, & Knoblich, 2011), a joint SNARC effect (Atmaca, Sebanz, Prinz, & Knoblich, 2008) and a joint dual-task effect (Liepelt & Prinz, 2011; Liepelt, Stenzel, & Lappe, 2012b).

However, there is recent evidence on the joint Simon task, which seems at odds with this task co-representation view (Dittrich et al., 2013; Dolk et al., 2011; Dolk, Hommel, Prinz, & Liepelt, 2013; Dolk, Hommel, Prinz, & Liepelt, 2014b; Guagnano, Rusconi, & Umiltà, 2010; Liepelt, Wenke, Fischer, & Prinz, 2011; Vlainic, Liepelt, Colzato, Prinz, & Hommel, 2010). As some of these studies were able to show that JSE-like effects can be induced for inanimate objects in a single go/nogo task, a referential coding account has been proposed for JSE-like effects (but see e.g., Müller et al., 2011a; Müller et al., in press; Stenzel et al., 2012; for a potential alternative interpretation of JSE-like effects assuming an anthropomorphic generalization of social co-representation effects to inanimate objects or agents). The referential coding account is based on the assumptions of ideomotor theory (James, 1890; Stock & Stock, 2004) and its extensions (Theory of Event Coding—TEC; Hommel et al., 2001). In accordance with TEC, the referential coding account assumes that one's own-produced actions are controlled by activation of feature codes representing perceivable sensory effects of that action. Further, externally triggered alternative actions (social and non-social) are represented by same or similar feature codes of that action. Accordingly, perceiving alternative action events that are similar to own intentional action events lead to an action selection/discrimination conflict that can be resolved by emphasizing (cf. intentional weighting principle; Memelink & Hommel, 2013) on action features that discriminate best between own and others actions in a given task context—referential coding (Hommel 1993a; Hommel et al., 2001; Dolk et al., 2011, 2013; for a review see Dolk et al., 2014a; see also Kornblum et al., 1990; Nicoletti & Umiltà, 1989; Treccani, Umiltá, & Tagliabue, 2006). In the case of the spatial JSE, the features that distinguish best between own and others actions are spatial response features. According to the intentional weighting principle, achieving this discrimination is implemented by attending more strongly to response location changing the weight of the spatial location codes. Hence, an overlap of the irrelevant spatial stimulus dimension and the now spatially coded own response dimension is reintroduced, which might explain the reappearance of the JSE in joint go/nogo task settings.

As the referential coding account assumes that internally and externally produced events are represented alike, the findings, which originally have been explained by task co-representation, can in principle also be explained by the referential coding account. For instance, if a co-actor is perceived more similar to oneself, e.g., when a co-actor is perceived as in-group member Müller et al., (2011b) or when actors are engaged in a positive (Hommel et al., 2009) or interdependent relationship (Iani et al., 2011; Ruys & Aarts, 2010), then representations thereof become more similar and hence more difficult to distinguish (see also Colzato, van den Wildenberg, & Hommel, 2013). To resolve this discrimination problem, a greater emphasis has to be given on (here spatial) features that can discriminate between own and other's actions (Hommel et al., 2009) and hence increasing the JSE. Even though the referential coding account is more comprehensive than the mainly socially explained task/action co-representation account and there is now evidence that JSE-like effects can be induced for event-producing objects there is still a lot of objection against this account by proponents assuming that phenomena like the JSE where a task is shared between two humans are due to task co-representation.

So far most studies investigating joint-action and task-sharing phenomena from a relative static perspective focusing on effects of joint-task performance considering only current trial performance. Only recently, some studies investigated whether the degree of conflict of a given trial defined in terms of S-R compatibility (low conflict: S-R compatible trial, high conflict: S-R incompatible trial) influences performance on consecutive trials (sequential modulation) in a joint go/nogo task (Liepelt et al., 2011; Liepelt, Wenke, & Fischer, 2013; Winkel et al., 2009, 2012). In the present study, we used a sequential approach to investigate the processes underlying joint action by providing salient unexpected (response) events of a co-actor and measuring its effect on S-R compatibility in the following trial. By applying this approach, we investigated the assumptions made by the task co-representation and the referential coding account. When jointly performing a task, it can be assumed that actions of one's own and actions of the other person are important information sources, especially when these actions are at odds with one's expectations. Representations of tasks and actions of oneself and the person with whom we share a task may not be statically implemented at the beginning of the task, but might be updated or even modulated according to unexpected changes of the situational circumstances.

Previous studies investigating the flexibility of cognitive control in individual participants by using unexpected changes in the environment have shown that these events lead to specific changes at electrophysiological and behavioral levels. The specific brain responses are interpreted as the detection and involuntarily orientation of attention toward the unexpected event and a reorientation of the attentional focus toward the task-relevant information (e.g., the rehearsal of the task instruction) (e.g., Berti, 2008; Schröger, 1996). On the behavioral level these processes are reflected by perturbed performance and prolonged response times (RTs) following presentation of unexpected stimuli (Berti, 2008; Berti & Schröger, 2004; Barcelo, Escera, Corral, & Periánez, 2006; Parmentier & Andrés, 2010; Parmentier, Elsley, Andrés, & Barcélo, 2011; Schröger & Wolff, 1998; Schröger, Giard, & Wolff, 2000). Investigating the impact of distracting events on attentional control, Parmentier and Andrés (2010) found significantly prolonged RTs when an unexpected/novel sound occurred on the preceding trial. Together with the findings at the electrophysiological level, Parmentier and Andrés concluded that following distraction by the unexpected/novel sound an updating of task sets is required in order "to guide future actions according to immediate goals and involve representations of stimulus–response mappings and abstract rules supported by the prefrontal cortex" (p. 73).

The aim of the present study was to test the different assumptions made by the task co-representation and the referential coding account for the JSE by using unexpected events and measuring the sequential adaptations thereof.

Experiment 1a

In Experiment 1a, we aimed to investigate whether in a joint go/nogo task unexpected events generated by a co-actor lead to a modulation of task processing and hence the JSE. Therefore, the co-actor (a confederate) infrequently responded together with the participant in a joint go/nogo task. The resulting double responses can be considered as unexpected events as they occur in rare cases (Barcelo et al., 2006). This approach reflects a fine-grained measure to test the predictions made by the task co-representation account, as it will indicate if and how co-represented task rules are updated online once they are implemented in a joint go/nogo task. According to the findings of the above-mentioned studies (Sebanz et al., 2005; Parmentier & Andrés, 2010), we expected that actors would update the implemented task set and task shares when perceiving unexpected response behavior of the co-actor in a joint go/nogo task. If so, one should assume to find prolonged responses after such an unexpected action of the co-actor, indicating that the unexpected event has been perceived. Further, according to the task co-representation account one should predict that the reorientation toward the task accompanying an updating of the joint-task set and represented task rules should lead to an increased JSE (joint go/nogo task).

On the other hand, following the assumptions of the referential coding account, one should predict that unexpected action events of the co-actor should lead to a change of intentional weighting (Memelink & Hommel, 2013) of the (spatial) response dimension, as on this dimension the unexpected event occurs. That is, because attention is attracted toward the relative spatial dimension (Berti, 2008; Schröger, 1996) when an unexpected action of the co-actor occurs, which changes the intentional weighting of the spatial feature of the response dimension. In turn, dimensional overlap between the horizontal stimulus and the response dimension is increased resulting in an enlarged JSE (joint go/nogo task).

Due to the fact that both accounts make the same predictions for the joint go/nogo task, we also manipulated the degree of interdependency between both go/nogo tasks in order to test different predictions of the two accounts. Task co-representation should be prevented when the alternative stimulus cannot be perceived and both go/nogo tasks are independent of each other (Sebanz et al., 2003, 2005; Ruys & Aarts, 2010). In order to meet these demands, both actors performed two different go/nogo tasks (joint independent go/nogo task) in different modalities (visual and auditory). Here, each person has the feeling to perform his/her individual go/nogo task merely beside another person, carrying out a different task.

For the joint independent go/nogo task, task co-representation should predict no effect of unexpected events on the size of the JSE if a JSE occurs at all. However, referential coding should predict an increase of the JSE in trials following unexpected events in both, the joint go/nogo and the joint independent go/nogo task. That is (a) because the JSE is not related to the specific task performed by the co-actor, but to the events produced, and (b) attention is attracted to the relative spatial response dimension after an unexpected event in both, the joint go/nogo and the joint independent go/nogo task.

Methods

Participants

Thirty-two participants took part in this experiment (24 females $M_{age} = 24.8$ years, $SD_{age} = 6.1$ years). Half of them were assigned to the joint go/nogo task (12 females $M_{age} = 25.6$ years, $SD_{age} = 7.8$ years) and the other half to the joint independent go/nogo task (12 females $M_{age} = 24.1$ years, $SD_{age} = 3.8$ years). All participants had normal or corrected to normal vision, and were naïve with regard to the hypothesis of the experiment. Twenty-nine participants were right handed. The participants were either paid € 7 or received course credit points as compensation for expenses. The study was conducted in accordance with the ethical standards laid down in the 1975 Declaration of Helsinki. All subjects gave their written informed consent before the experiment was carried out.

Apparatus and stimuli

The experiment took place in a dimly lit room with a 19 in. computer monitor placed in the middle of a desk and two chairs that were placed side-by-side in front of the monitor. Participants were always seated on the right chair, whereas a confederate acting as co-actor sat on the left side. Responses of the participant and the confederate were registered with two response buttons placed on the desk at a distance of 25 cm from each other (12.5 cm to the left and 12.5 cm to the right from the imagined vertical midline of the monitor, respectively). Participants and confederate used their right index finger to operate their response button.

Stimuli were presented on the monitor in white on a black background at a viewing distance of approximately 60 cm. The stimuli consisted of squares and diamonds (1.9° × 1.9°). All trials started with a fixation cross (0.9° × 0.9°), displayed at the center of the monitor. After 250 ms, either a square or a diamond was randomly presented either to the left or the right side of the fixation cross. The stimulus remained on the screen for 150 ms. Responses had to be given within 2500 ms starting with onset of the stimulus (see Fig. 1).

Procedure

Participants were randomly assigned to one of two task sets. In the joint go/nogo task participants were instructed that they will jointly perform a visual reaction time task and that within each trial either a square or a diamond will appear either on the left or on the right side of the monitor. The participant's task was to press the response key whenever a diamond appeared on the screen, and to withhold responses when a square appeared. The co-actor (i.e., confederate) was instructed to press the response key whenever a square appeared on the screen, but not to respond when a diamond appeared. Participants of the joint independent go/nogo task were instructed that both persons would perform separate reaction time tasks. The participants received the same instruction as participants of the joint go/nogo task set (i.e., in each trial either a square or a diamond would be presented either on the left or right side of the monitor, and a response to the diamond was required). Different from the joint go/nogo task set, the co-actor (i.e., confederate) was now instructed that either a high- or a low-pitched tone will be randomly presented via headphones either to the left or to the right ear and that he had to press the response key whenever a high-pitched tone was presented and to withhold response when a low-pitched tone appeared. Therefore, although participants were aware of the co-actors task, they could not predict the co-actor's responses, as they could not hear the tones the co-actor responded to. To control for perceptual differences between the joint go/nogo task and the joint independent go/nogo task, participants and the confederate wore headphones in both task sets during the entire experiment. Please note that in both task sets participants and co-actors were present during task instructions so that participants were aware of the respective task the co-actor had to perform. In both task sets, unexpected double response events occurred in 7 % of all trials. These rare events were triggered by the unexpected response of the confederate that occurred simultaneously with the response of the participant when it was the participant's turn (i.e., when a diamond was presented on the monitor). In half of the double response trials, the diamond presented was S-R compatible (i.e., presented to the right of the fixation cross) and in the other half, the diamond presented was S-R incompatible (i.e., presented to the left of the fixation cross). In the remaining trials, regular single response events were performed either by the participant (i.e., when a diamond was presented; half S-R compatible and the other half S-R incompatible) or the confederate (i.e., when a square was presented; half S-R compatible and the other half S-R incompatible).[1] Task instructions appeared on the screen at the beginning of the experiment.

To familiarize participants with the task, they performed six practice trials before starting the experimental block. Participants were informed that simultaneous responses could happen. In the joint go/nogo task set if one of them makes an error. In the joint independent go/nogo task set when the visual (participant) and the auditory stimuli (co-actor) are presented at the same time both requiring a response. In fact, both task sets were identical regarding the execution of regular single and rare/unexpected double responses. In the joint go/nogo task, the rare double response relates to an erroneous response of the co-actor to a visual stimulus that the participant could perceive (i.e., a violation of the task rule). In contrast, in the joint independent go/nogo task the co-actor's response was a correct response to an auditory stimulus that participants could not perceive.

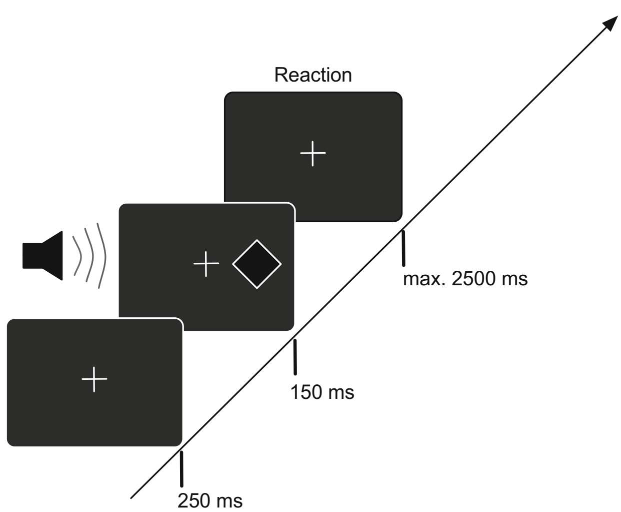

Fig. 1 Stimulus sequence in each trial. Trials started with a fixation cross displayed for 250 ms. Then, either a square or a diamond was presented for 150 ms either on the *left* or *right* side of the monitor. The participants had to press the response button within 2500 ms. In trials in which the confederate had to respond (i.e., whenever a square was displayed or in 7 % of the trials in which a diamond was displayed), a tone was presented via headphones while the visual stimulus remained on screen

[1] We controlled the amount of single and double responses on the confederate side in both task sets by presenting one tone (350 Hz) via headphones to the confederate. This was done to minimize erroneous responses on the confederate's side. In both task sets, this tone was always presented via the headphones of the confederate when a square was presented on the monitor (i.e., in 50 % of all trials) and in rare cases (7 % of all trials) this tone was also presented when a diamond was presented on the monitor resulting in the required double response.

Each participant completed four experimental blocks consisting of 120 trials each. The experimental blocks were separated by short breaks.

Rating data

As a manipulation check to test whether participants perceived the joint go/nogo task and the joint independent go/nogo task different, we acquired rating data. At the end of the experiment, participants had to complete a questionnaire, in which they were asked to indicate how much they felt as a team with the co-actor during joint-task performance and to rate the perceived collaboration in the joint go/nogo and the joint independent go/nogo task. Participants had to respond to both questions using a 5-point scale ranging from not at all to fully. Furthermore, participants were asked to rate the perceived cordiality of the co-actor on a 9-point scale ranging from not at all cordially to very cordially. When the manipulation of task instruction was successful, we expected to find lower scores for the joint independent go/nogo task group as compared to the joint go/nogo task group.

Results

Mean RTs were analyzed as a function of setting (joint go/nogo task vs. joint independent go/nogo task), response type in trial *N*-1 (single left response confederate$_{N\text{-}1}$ vs. double response$_{N\text{-}1}$ vs. single right response participant$_{N\text{-}1}$) and compatibility (compatible vs. incompatible) with the latter two factors as within-subjects factors and setting as between-subjects factor. Only data from the real participants were analyzed. The first trial in a block and trials in which responses were either incorrect on the current (1.2 %) or the previous trial (1.3 %) were excluded. RTs differing more than 2.5 standard deviations from the mean RTs of each participant and each combination of the factors setting, response type in trial *N*-1 and compatibility were excluded from further analysis (1.8 %; RTs ranging from 195 ms to 894 ms over all conditions and participants). Error rates were rather low in both task sets, with 1.5 % in the joint go/nogo task set and 0.9 % in the joint independent go/nogo task set. Because of the low number of errors, we did not analyze error rates any further.

To gain further insight into the persistence of the sequential modulation of the JSE following unexpected double response events, we ran an additional repeated measures analysis of variance (ANOVA) with setting (joint go/nogo task vs. joint independent go/nogo task) as between-subjects factor and response type in trial *N*-2 (single left response confederate$_{N\text{-}2}$ vs. double response$_{N\text{-}2}$ vs. single right response participant$_{N\text{-}2}$) and compatibility (compatible vs. incompatible) as within-subjects factors.[2] Therefore, the first and second trial in each block, trials with erroneous responses at the penultimate trial (1.1 %) and trials with RTs differing more than 2.5 standard deviations from the mean RT of each participant and each combination of the factors setting, response type in *N*-2 and compatibility (1.8 %) were excluded from further analysis (RTs ranging from $RT_{min} = 251$ ms to $RT_{max} = 602$ ms).

Additionally, we calculated Bayesian posterior probabilities for the occurrence of the null (H_0) and the alternative (H_1) hypothesis given the obtained data (Masson, 2011; Wagenmakers, 2007). This method allows one to directly quantify evidence in favor of the alternative hypothesis and—more important— in favor of the null hypothesis, instead of just rejecting the alternative hypothesis by providing the exact probability of their occurrence, with values ranging from 0 (i.e., no evidence) to 1 (i.e., very strong evidence; see Raftery, 1995 for a classification).

Effects of N-1 response type on the JSE

The ANOVA revealed that the main effect of the factor setting, $F(1,30) = 1.49$, $p = 0.231$, partial $\eta^2 = 0.05$, $p(H_0|D) = 0.72$, as well as the interaction effects of setting × compatibility, $F(1,30) = 0.002$, $p = 0.963$, partial $\eta^2 < 0.001$, $p(H_0|D) = 0.85$, and setting × response type$_{N\text{-}1}$, $F(2,60) = 0.14$, $p = 0.869$, partial $\eta^2 = 0.005$, $p(H_0|D) = 0.98$, were far from significance, indicating that setting did neither affect the size of the JSE nor the modulation of the JSE by unexpected double response events.

We found a significant effect of compatibility, $F(1,30) = 21.76$, $p < 0.001$, partial $\eta^2 = 0.42$, $p(H_1|D) = 0.99$, showing a JSE with faster RTs of the current trial in S-R compatible trials (339 ms) than S-R incompatible trials (353 ms). Furthermore, the main effect of response type$_{N\text{-}1}$ was significant, $F(2, 60) = 4.55$, $p = 0.05$, partial $\eta^2 = 0.13$, $p(H_1|D) = 0.59$, with faster RTs when participants responded alone in the previous trial (341 ms) as compared to trials following double responses (352 ms), ($p < 0.01$). RTs of trials following single responses of the confederate (347 ms) did not differ significantly from trials following double responses ($p = 0.202$). Most relevant for the present research question, we found a significant interaction of compatibility × response type$_{N\text{-}1}$, $F(2, 60) = 3.68$, $p < 0.05$, partial $\eta^2 = 0.11$, $p(H_1|D) = 0.62$. The JSE was (more than) twice as large following unexpected double responses (22 ms) as compared to trials following single responses of the participants (11 ms) or the

[2] To compute a separate ANOVA considering Response type in N-2, Response type in N-1 and Compatibility the amount of trials was too low due to the planned low number of double response trials and hence results of such an ANOVA would not be very meaningful.

confederate (9 ms; see Fig. 2; Table 1). Finally, the three-way interaction of setting × response type$_{N\text{-}1}$ × compatibility proofed not to be reliable, $F(2, 60) = 0.003$, $p = 0.997$, partial $\eta_2 < 0.001$, $p(H_0|D) = 0.98$.

Effects of N-2 response type on the JSE

The ANOVA revealed neither a significant main effect of the factor setting, $F(1, 30) = 1.35$, $p = 0.254$, partial $\eta^2 = 0.04$, $p(H_0|D) = 0.74$, nor significant interaction effects with the factor setting × response type$_{N\text{-}2}$, $F(2, 60) = 0.257$, $p = 0.774$, partial $\eta^2 = 0.008$, $p(H_0|D) = 0.98$, and setting × compatibility, $F(1, 30) = 0.093$, $p = 0.763$, partial $\eta^2 = 0.003$, $p(H_0|D) = 0.84$. Furthermore, the three-way interaction of setting × response type$_{N\text{-}2}$ × compatibility was not significant, $F(2, 60) = 0.125$, $p = 0.883$, partial $\eta^2 = 0.004$, $p(H_0|D) = 0.98$.

We found a significant main effect of compatibility, $F(1, 30) = 23.88$, $p < 0.001$, partial $\eta^2 = 0.44$, $p(H_1|D) = 0.99$, with faster RTs in S-R compatible trials (336 ms) as compared to S-R incompatible trials (348 ms).

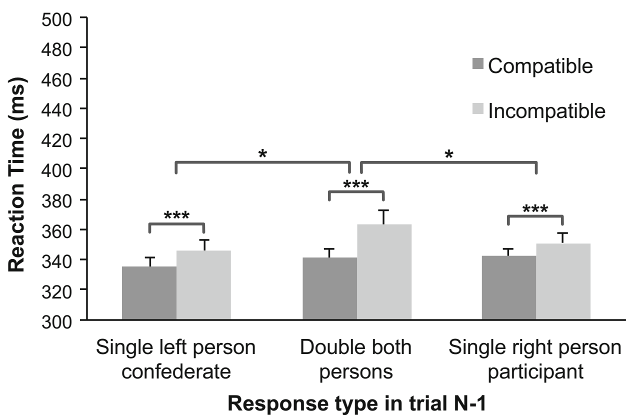

Fig. 2 Mean reaction times of Experiment 1a as a function of response type in trial *N*-1 and compatibility collapsed over both settings (joint go/nogo task and joint independent go/nogo task). The *lower brackets* indicate significant differences between compatible and incompatible trials. The *upper brackets* indicate significant differences between the JSEs. *Error bars* represent standard errors of the means. *$p < 0.05$, ***$p < 0.001$

Table 1 Mean reaction times (in ms) of Experiment 1a for response type in *N*-1, response type in *N*-2 and compatibility collapsed over both settings (joint go/nogo task and joint independent go/nogo task)

	N-1		*N*-2	
	C	IC	C	IC
Single left person confederate	342	351	348	358
Double both persons	341	363	334	347
Single right person participant	335	346	329	339

C compatible, IC = incompatible

Furthermore, the main effect of response type$_{N\text{-}2}$ proofed to be significant, $F(2, 60) = 16{,}95$, $p < 0.001$, partial $\eta^2 = 0.36$, $p(H_1|D) > 0.99$, with significant longer RTs after single responses of the confederate in the penultimate trial (353 ms) as compared to RTs following single responses of the participant (334 ms), ($p < 0.001$) and double responses of both in the penultimate trial (341 ms), ($p < 0.01$). Most interestingly for the purpose of the current analysis, the interaction of response type$_{N\text{-}2}$ × compatibility was not reliable, $F(2, 60) = 0.22$, $p = 0.80$, partial $\eta_2 = 0.007$, $p(H_0|D) = 0.98$ (see Table 1).

Rating data

Participants of the joint independent go/nogo task (1.13) significantly felt less as a team as compared to the joint go/nogo task group (2.00), ($p < 0.01$, one-tailed). Furthermore, participants of the joint independent go/nogo task group (1.94) perceived marginally significant less collaboration between them and the co-actor than the joint go/nogo task group (2.44), ($p = 0.058$, one-tailed). Furthermore, participants of the joint go/nogo task group perceived the co-actor to be more cordially (7.34) than participants of the joint independent go/nogo task group (6.58), ($p < 0.05$, one-tailed). The rating data show that participants of the joint and the joint independent go/nogo task groups perceived the experimental situation differently and suggest that the task manipulation was successful.

Experiment 1b

The task co-representation account assumes that in a joint Simon task participants co-represent the alternative task rule and the action of the other's disposal in a functionally equivalent way as their own (Sebanz et al., 2003, 2005). In Experiment 1b we aimed to test this assumption by analyzing how participants update their task representations following unexpected events in a standard Simon task in comparison to the joint go/nogo task of Experiment 1a. Therefore, participants performed a visual standard Simon task. As in Experiment 1a, we provided rare/unexpected double responses.

In line with previous findings (e.g., Simon, & Rudell, 1967), we expected to find a typical SE with faster responses in S-R compatible trials compared to S-R incompatible trials. According to the findings of Parmentier and Andrés (2010), we further assumed to find prolonged RTs after unexpected double responses as compared to RTs following regular single response events. According to the task co-representation account one should predict to find the same (or at least a similar) response pattern in the standard Simon task and the joint go/nogo task of

Experiment 1a. That is, if task representations are updated after unexpected events the SE is sequentially increased compared to regular single response events in the standard Simon task. Whereas, the referential coding account of the joint Simon effect does not assume a functional equivalence between the joint and the standard Simon task. Referring to previous findings investigating processes underlying the standard Simon effect, one might assume to find the SE to be diminished following unexpected events either due to suppression or a spontaneous decay of the primed automatic response (e.g., Hommel, 1993b, 1994; De Jong et al., 1994).

Methods

Participants

Sixteen new participants took part in Experiment 1b (11 females; $M_{age} = 22.8$ years, $SD_{age} = 4.7$ years). All participants except of two were right-handed and all had normal or corrected to normal vision. They were all naïve with regard to the hypothesis of the experiment. Participants were treated in the same way as participants in Experiment 1a.

Apparatus and stimuli

The apparatus and stimuli were the same as in Experiment 1a. In the present experiment participants were seated centrally in front of the monitor with a viewing distance of approximately 60 cm. Participants operated the right response button with the right index finger and the left response button with the left index finger.

Procedure

Participants were instructed to respond with a left button press whenever a square was displayed on the monitor and to respond with right button press whenever a diamond was displayed on the monitor. Each participant completed four experimental blocks (separated by short breaks) each consisting of 120 trials. By presenting both stimuli simultaneously (half of the trials compatible and the other half incompatible) unexpected double responses were acquired in 7 % of all trials. In the remaining trials either a square or a diamond was presented either to the left or the right of the fixation cross (half compatible and the other half incompatible to the required response). Before task execution, participants performed a short block consisting of 6 practice trials. Participants were informed that it could happen that both stimuli will be presented, which requires a response with both response buttons.

Results

Mean RTs were analyzed as a function of Response type in trial *N*-1 (single left response$_{N\text{-}1}$ vs. double response$_{N\text{-}1}$ vs. single right response$_{N\text{-}1}$), and compatibility (compatible vs. incompatible). Prior to statistical analysis, the first trial in each block and incorrect responses either on the current (5.3 %) or the previous trial (5.2 %) were excluded. In double response trials only RTs of the response that was executed first were considered for statistical analysis.[3] Additionally, RTs differing more than 2.5 standard deviations from the mean RT of each participant and factorial combination of the factors response type in trial *N*-1 and compatibility (2.3 %) were excluded from further analysis (RTs ranging from $RT_{min} = 228$ ms to $RT_{max} = 1553$ ms). To analyze the dynamic of the SE modulation following unexpected double response events an additional ANOVA was computed considering response type in trial *N*-2 (single left response$_{N\text{-}2}$ vs. double response$_{N\text{-}2}$ vs. single right response$_{N\text{-}2}$) and compatibility (compatible vs. incompatible) as factors. Therefore, additionally, the second trial of each block, trials with incorrect responses at the penultimate trial (5.3 %) and trials with RTs differing more than 2.5 standard deviations from the mean RT of each participant and factorial combination of the factors response type in trial *N*-2 and compatibility (2.5 %) were excluded (RTs ranging from $RT_{min} = 228$ ms to $RT_{max} =$ 1212 ms).

Effects of N-1 response type on the SE

The ANOVA revealed a significant main effect of response type$_{N\text{-}1}$, $F(2, 30) = 31.76$, $p < 0.001$, partial $\eta^2 = 0.68$, $p(H_1|D) > 0.99$, with significant longer RTs following trials requiring a double response (563 ms) as compared to trials after single right response (467 ms), ($p < 0.001$) and after single left response (465 ms), ($p < 0.001$). The main effect of compatibility was not significant, $F(1, 15) = 0.013$, $p = 0.911$, partial $\eta^2 = 0.001$, $p(H_0|D) = 0.80$, which is explained by the significant two-way interaction of response type$_{N\text{-}1}$ × compatibility, $F(2, 30) = 22.98$, $p < 0.001$, partial $\eta^2 = 0.61$, $p(H_1|D) > 0.99$. The SE was reversed and enlarged following double responses (−31 ms) as compared to trials following single right responses (9 ms) and single left responses (21 ms; see Fig. 3; Table 2).

[3] A separate ANOVA considering both responses in double response trials (by averaging both RTs) revealed the same results indicating that response buttons for both stimuli were pressed in close temporal proximity.

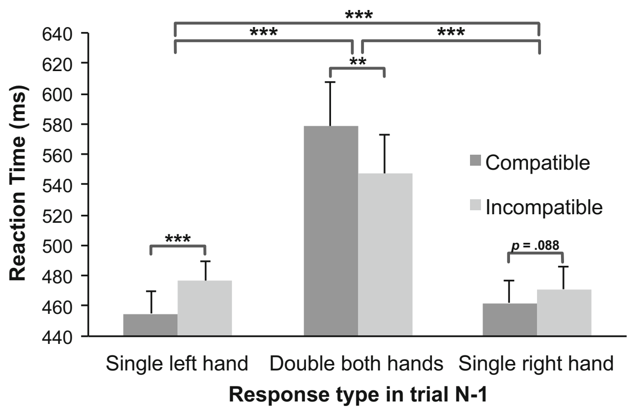

Fig. 3 Mean reaction times of Experiment 1b (two-choice Simon task) as a function of response type in trial *N*-1 and compatibility. The *lower brackets* indicate significant differences between compatible and incompatible trials. The *middle* and *upper brackets* indicate significant differences between the SEs. *Error bars* represent standard errors of the means. $^{**}p < 0.01$, $^{***}p < 0.001$

Table 2 Mean reaction times (in ms) of Experiment 1b (two-choice Simon task) for response type in *N*-1, response type in *N*-2 and compatibility

	N-1		*N*-2	
	C	IC	C	IC
Single left hand	455	476	466	479
Double both hands	578	547	457	467
Single right hand	462	471	464	480

C compatible, *IC* incompatible

Effects of N-2 response type on the SE

The ANOVA revealed a significant main effect of compatibility, $F(1,\ 15) = 7.68$, $p < 0.05$, partial $\eta^2 = 0.34$, $p(H_1|D) = 0.87$, with longer RTs in S-R incompatible trials (475 ms) as compared to S-R compatible trials (462 ms). Furthermore, the main effect of response type$_{N\text{-}2}$, $F(2, 30) = 2.79$, $p = 0.078$, partial $\eta^2 = 0.16$, $p(H_0|D) = 0.68$, was marginally significant with shortened RTs when double responses were performed in *N*-2 (462 ms) as compared to RTs with single right response (472 ms) and with single left response (472 ms) in *N*-2. However, the Bayes probability suggests that RTs do not differ depending on the response type in the penultimate trial. The interaction of response type$_{N\text{-}2}$ × compatibility was not reliable, $F(2,\ 30) = 0.260$, $p = 0.773$, partial $\eta^2 = 0.017$, $p(H_0|D) = 0.96$ (see Table 2).

Discussion

In Experiment 1a we investigated whether task co-representation is sequentially updated or intentional weighting is adjusted following unexpected double response events during performance of a joint go/nogo task resulting in an increased JSE. In order to differentiate between both accounts, we further tested whether a modulation of the JSE following unexpected events occurs, when the establishment of the co-actor's S-R mapping is prevented and independency between both go/nogo tasks is given (joint independent go/nogo task). In Experiment 1b, we tested the functional equivalence assumption of the task co-representation account between a standard two-choice Simon task and a joint go/nogo Simon task. In line with the findings of Parmentier and Andrés (2010), we found prolonged response times in trials following unexpected double response events compared to regular single response events in the joint go/nogo Simon tasks of Experiment 1a and the standard two choice Simon task of Experiment 1b. While we found a reliable JSE in the joint go/nogo Simon task of Experiment 1a, we did not observe a reliable SE in the standard Simon task of Experiment 1b.

Critically for our research question the type of response in the preceding trial modulated the JSE (Experiment 1a). In line with the predictions made by both accounts, in the joint go/nogo task the JSE significantly increased in size when both actors responded in the preceding trial (unexpected event) as compared to trials following single responses of the participant or the confederate (regular events). However, contrary to the prediction of task co-representation, we also found a significant JSE in the joint independent go/nogo task that was increased in size after unexpected double responses as compared to trials following single responses. Both, the findings of a JSE and of an increased JSE in trials following unexpected events in the joint go/nogo and the joint independent go/nogo task are in line with the assumptions of the referential coding account. Referential coding assumes that the JSE is due to the similarity between internally activated and externally produced events (i.e., action discrimination problem) and not the specific task performed by the co-actor. Referential coding can explain the modulation of the JSE after an unexpected response event by assuming that attention is attracted to the relative spatial response dimension after an unexpected event further increasing the discrimination problem and its resolution by intentional weighting. Further, in the standard Simon task of Experiment 1b, the SE following unexpected double responses was reversed and enlarged compared to the SE following regular single response events, which contradicts the functional equivalence assumption of the task co-representation account, but is in line with previous findings investigating the mechanisms underlying the SE (e.g., Hommel 1993b, 1994; De Jong et al., 1994). Finally, for both experiments we found that the JSE was not modulated by unexpected events in trial N-2 suggesting that the effects of unexpected double response events are only short lasting effects.

However, although the rating data suggest that participants of the joint independent go/nogo task perceived the task situation as more independent (as compared to participants of the joint go/nogo task), one may argue that they may have re-conceptualized the task rules of the co-actor. That is, next to the unexpected double responses the confederate always responded when the alternative visual stimulus of the participant's go/nogo task was presented, so that participants may have established an S-R mapping by means of the alternative visual stimulus. This assumption could in principle also explain the finding of an increased JSE after unexpected events in the joint independent go/nogo task.

Experiment 2

The aim of Experiment 2 was to test if the increased JSE following unexpected double response events found in the joint independent go/nogo task group of Experiment 1a might be due to a re-conceptualization of the co-actor's task rules by the participant. To rule out this alternative, participants performed the joint independent go/nogo task of Experiment 1a, but now the co-actor responded in nearly each trial and rare single responses of the participant were unexpected events. After an unexpected single response event there should be no update of the joint-task rule.

According to task co-representation we expected to find no modulation of the JSE by the unexpected events. While according to the referential coding account, one should predict to find an increased JSE following rare (unexpected) single responses of the participant as compared to regular response events. That is, because also unexpected single response events should attract attention toward the response location and hence leading to increased intentional weighting of the spatial response dimension.

Methods

Participants

Sixteen new participants took part in Experiment 2 (7 females; $M_{age} = 25.1$ years, $SD_{age} = 4.3$ years). Fourteen participants were right handed and all had normal or corrected to normal vision. They were all naïve with regard to the hypothesis of the experiment. Participants were treated as in Experiment 1a. One participant had to be excluded because RTs were not recorded due to a technical problem. One more participant had to be excluded due to high error rates exceeding two standard deviations of the mean error rate.

Apparatus and stimuli

The apparatus and stimuli were the same as in Experiment 1a.

Procedure

The procedure was similar to the joint independent go/nogo task of Experiment 1a. Unlike in the joint independent go/nogo task, double responses were now regular events whereas single responses of the participants were unexpected events. In the present experiment participants responded in 50 % of all trials (i.e., 10 % single responses when a diamond was presented and 40 % double responses together with the confederate when a diamond was presented). The confederate responded in 90 % of all trials (i.e., 50 % single responses when a square was presented and 40 % double responses together with the participant when a diamond was presented). Participants performed four blocks separated by short breaks. Each block consisted of 150 trials.

Results

Mean RTs were analyzed in the same way as in Experiment 1a leading to removal of incorrect responses (1.3 % current trial and 1.3 % previous trial) and 2.1 % RT outliers (RTs ranging from $RT_{min} = 203$ ms to $RT_{max} = 841$ ms). In the N-2 analyses 1.3 % errors and 2.0 % RT outliers (RTs ranging from $RT_{min} = 172$ ms to $RT_{max} = 778$ ms) were excluded.

Effects of N-1 response type on the JSE

The repeated measures ANOVA revealed a marginally significant main effect of compatibility, $F(1, 13) = 3.87$, $p = 0.071$, partial $\eta^2 = 0.23$, $p(H_1|D) = 0.62$, with faster RTs in S-R compatible trials (343 ms) as compared to S-R incompatible trials (351 ms). There was a significant effect of response type$_{N\text{-}1}$, $F(2, 26) = 3.58$, $p < 0.05$, partial $\eta^2 = 0.22$, $p(H_1|D) = 0.52$, showing increased RTs following single responses of the confederate (353 ms) as compared to trials following double responses (342 ms), ($p < 0.01$). RTs following rare single responses of the participants (344 ms) did not differ significantly from RTs following double responses or single responses of the confederate ($p = 0.150$). The interaction of compatibility × response type$_{N\text{-}1}$ was significant, $F(2, 26) = 5.09$, $p < 0.05$, partial $\eta^2 = 0.28$, $p(H_1|D) = 0.79$, with an increased JSE following rare single responses of the participants (22 ms) as compared to the JSE following single responses of the confederate (0 ms) and trials following double responses (2 ms; see Fig. 4; Table 3).

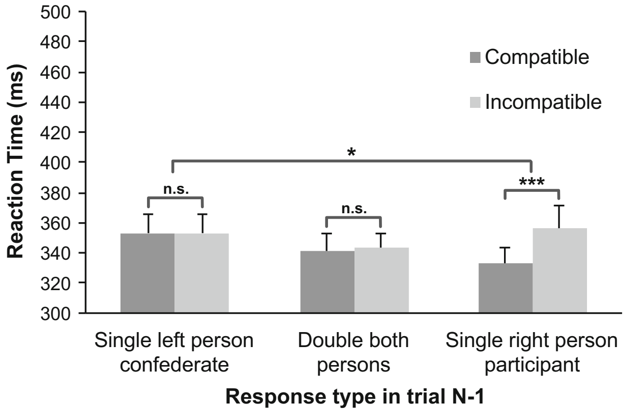

Fig. 4 Mean reaction times of Experiment 2 (joint independent go/nogo task) as a function of response type in trial *N*-1 and compatibility. The *lower brackets* indicate significant and not significant differences between compatible and incompatible trials, respectively. The *upper bracket* indicates a significant difference between the JSEs. *Error bars* represent standard errors of the means. $*p < 0.05$, $***p < 0.001$, n.s. $p > 0.05$

Table 3 Mean reaction times (in ms) of Experiment 2 (joint independent go/nogo task) for response type in *N*-1, response type in *N*-2 and compatibility

	N-1		*N*-2	
	C	IC	C	IC
Single left person confederate	353	353	355	360
Double both persons	341	343	334	340
Single right person participant	333	356	337	337

C compatible, *IC* incompatible

Effects of N-2 response type on the JSE

The ANOVA revealed a significant main effect of response type$_{N\text{-}2}$, $F(2, 26) = 20.66$, $p < 0.001$, partial $\eta^2 = 0.61$, $p(H_1|D) > 0.99$, with longer RTs when the confederate responded alone in *N*-2 (358 ms) as compared to RTs when the participant responded alone (337 ms), ($p = 0.001$) and when both responded (337 ms) in *N*-2, ($p < 0.001$). The main effect of compatibility, $F(1, 13) = 0.76$, $p = 0.39$, partial $\eta^2 = 0.06$, $p(H_0|D) = 0.72$, and the interaction of response type$_{N\text{-}2}$ × compatibility, $F(2, 26) = 0.56$, $p = 0.58$, partial $\eta^2 = 0.04$, $p(H_0|D) = 0.94$, were not reliable (see Table 3).

Rating data

Participants of the joint independent go/nogo task of Experiment 2 (1.43) significantly felt less as a team as compared to the joint go/nogo task group of Experiment 1a (2.00), ($p < 0.05$, one-tailed). Furthermore, the participants of the joint go/nogo task group of Experiment 1a perceived the co-actor to be more cordially (7.34) than participants of the current joint independent go/nogo task group (6.86), ($p < 0.05$, one-tailed). The rating data suggest that participants of the current experiment perceived the experimental situation differently to the participants of the joint go/nogo task group of Experiment 1a suggesting that the task manipulation was successful.

Discussion

Experiment 2 was designed to investigate whether increased JSEs following unexpected double response events found in the joint independent go/nogo task group of the previous experiment were due to the re-conceptualization of the co-actor's task rules by the participant. Hence, in the present experiment the co-actor responded in nearly each trial and we used rare single responses of the participant as unexpected events. We found a marginally significant JSE, which was significantly increased following unexpected single responses of the participant, which is in line with predictions of the referential coding account. The presence of unexpected single response events seems to have attracted attention toward the response location and hence led to an increased JSE. Again, we found no modulation of the JSE in *N*-2 responses indicating that the effects induced by the perception of an unexpected event is short lasting. A further interesting finding that we obtained in Experiment 2 was the finding of no JSEs following frequent regular events. This finding might suggest that when the co-actor is responding on nearly every trial, spatial features must not longer be emphasized in order to discriminate own and other's actions.

General discussion

The present study aimed to test the assumptions made by the task co-representation and the referential coding account by introducing rare unexpected events initiated by a co-actor in a joint go/nogo task and in a joint independent go/nogo task. In Experiment 1a, we found a significantly increased JSE following rare and therefore unexpected double response events in a joint go/nogo task where two persons collaboratively share the task, which is in line with predictions of the task co-representation and the referential account. However, we also found an increased JSE after unexpected double responses in the joint independent go/nogo task, in which two persons performed two separate tasks (visual and auditory task), which is at odds with the task co-representation account, but in line with the assumptions of referential coding. This effect was gained, even though the participant performing the visual task could not directly perceive the auditory stimuli of the co-actor, as these stimuli were presented via headphones. According to the task co-representation account one may wonder why a JSE should appear at all in the joint independent go/nogo task as no link of the co-actor's stimulus and response should have been established. Whereas, according to the referential coding account this finding makes sense, when considering that own actions are referentially coded to alternative action events independently of the exact task of the co-actor.

Going one step further, Experiment 1b tested one of the core assumptions of task co-representation holding that task representations in a joint go/nogo task and a standard two-choice Simon task are functionally equivalent. In contrast to the joint go/nogo task of Experiment 1a, we found a reversed and enlarged SE following unexpected double response events in the standard Simon task indicating that functional equivalence between the standard Simon task and the joint go/nogo task is not given. The finding that rare and unexpected events trigger different effects in these two types of Simon tasks suggests that the standard Simon task and the joint go/nogo task may not produced by a single unitary mechanism.

In Experiment 2 we tested if the increased JSE following unexpected double response events observed in the joint independent go/nogo task group of Experiment 1a is due to a re-conceptualization of the co-actor's task rule and hence an establishment of an action link between the alternative visual stimulus (of the participants go/nogo task) and the response actions from the co-actor. Letting the co-actor responding in nearly each trial to prevent re-conceptualization and thus making single responses of the participant the rare and therefore unexpected event, showed that the JSE significantly increased after unexpected single responses. These findings, again, provide support for the view that the JSE in joint go/nogo tasks is due to referential coding of one's own and the other's actions instead of a joint-task representation including the other's task shares (i.e., task co-representation).

Taken together, although the findings in the joint go/nogo task of Experiment 1a are in line with the predictions made by the task co-representation account, the further findings provide evidence against task co-representation as the underlying mechanism of the JSE in human–human joint action scenarios. However, taking referential coding into account, the present findings can be explained in a straightforward way (Dolk et al., 2011, 2013). As, according to this account, dimensional overlap and hence the JSE re-emerges due to an action discrimination problem between a person's own and alternative (action) events. To resolve this discrimination problem participants emphasize the weight of event features (intentional weighting) that discriminate best between own and others actions in a given task context (Dolk et al., 2013; Hommel 1993a; Kornblum et al., 1990; Memelink & Hommel, 2013). In the present study, the same discrimination problem is present in the collaborative joint go/nogo and the joint independent go/nogo task, which explains why the JSE is present in both tasks independent of the visual or auditory stimulus modality. As the presence of the co-actor's response events produces the discrimination problem, there is no need to perceive the alternative stimuli to induce a JSE. The unexpected action events of the co-actor seem to attract attention toward the relative spatial response dimension changing the need for intentional weighting (Experiments 1a and 2). In turn dimensional overlap between the horizontal stimulus and the response dimension is increased resulting in a stronger S-R compatibility effect after unexpected events in joint go/nogo tasks.

The findings of Experiment 1b suggest that functionally different mechanisms may underlie joint go/nogo Simon and standard Simon effects. The decrease of the SE after unexpected events in the standard Simon task is in line with previous findings investigating the mechanisms underlying the SE (e.g., Hommel 1993b, 1994; De Jong et al., 1994). Since we found a negative SE after unexpected events, one might assume that this reflects a selective inhibition of automatically activated responses (Ridderinkhof, 2002; Ridderinkhof, van den Wildenberg, Wijnen, & Burle, 2004). One might assume that unexpected double responses may have induced a severe form of conflict and conflict adaptation in the standard Simon task (Botvinick, Braver, Barch, Carter, & Cohen, 2001) that may have led to a reversal of the SE. However, this issue needs further testing.

A potential limitation of the present study is that the joint go/nogo task and the standard Simon task might not be fully comparable due to a difference how unexpected double responses were established. While in the joint go/nogo task only one stimulus was presented and the co-actor's response produced the unexpected event (double responses), unexpected double responses in the standard Simon task were introduced by presenting both visual stimuli simultaneously (as this seems to be the most natural way to induce an unexpected double response in one person). However, we think that the occurrence of double responses can in principle assessed to be comparable regarding their unexpectedness in both experiments, as these are still rare and hence unexpected events, which we assume led to an updating of the task set, which would be the same manipulation as in the joint and joint independent go/nogo task groups. We furthermore investigated the modulation of task processing on the following trial. Although, stimulus processing on the previous trial might have taken longer in the standard Simon task (as both stimuli had to be perceived and identified instead of one), a representation of both responses should have been activated similar to those in Experiment 1a.

One might further question the comparability of both tasks due to the slower responses in the standard Simon as compared to the joint go/nogo tasks. Yet, the finding of our study replicates a typical finding of studies comparing the JSE in joint go/nogo tasks (e.g., Sebanz et al., 2003; Liepelt et al., 2011). Our findings of a functional difference between the standard Simon and the joint go/nogo tasks by measuring effects of unexpected events seem to be in line with recent findings showing that RT-distributions differ between the standard Simon (e.g., Hommel, 1994; De Jong et al., 1994) and joint go/nogo tasks (Dolk et al., 2014a; Liepelt et al., 2011). In this respect it makes much sense that also response latencies differ between joint go/nogo tasks and the standard Simon task, which are typically more comparable to the level of an individual go/nogo task (e.g., Sebanz et al., 2003; Liepelt et al., 2011).

Another potential limitation of the present study is that participants may have perceived unexpected double responses functionally different in the joint go/nogo task and in the joint independent go/nogo task. This would make it difficult to compare these two conditions. That is, participants in the joint go/nogo task perceived double responses as errors on the confederate's part, because they believed that the co-actor responded to the square symbol, while responses should not be perceived as an error in the joint independent go/nogo task, because participants believed that the co-actor responded to tones. However, it has been shown that error perception and perception of infrequent (unexpected) events elicit similar effect patterns on a behavioral and an electrophysiological level (Notebaert et al., 2009; Nunez Castellar, Kühn, Fias, & Notebaert, 2010; Notebaert, & Verguts, 2011; Berti, Roeber, & Schröger, 2004), which undermines the assumption of a functional difference between the joint go/nogo task and in the joint independent go/nogo task.

While other studies investigating sequential dependencies on joint-task performance (e.g., Liepelt et al., 2011, 2013; Winkel et al., 2009) took into account the stimulus compatibility of current and preceding trials, we did not consider this aspect in the current study. Here, we focused on performance changes that are due to unexpected events (double and single responses). An analysis additionally including sequential variations of S-R compatibility effects would require an enormous increase in the amount of trials especially of those referring to rare unexpected events, which would have changed task requirements and the research focus. However, this would be an interesting direction for future studies.

In conclusion the present study shows that a more detailed investigation of the mechanisms underlying joint action by analyzing sequential effects of unexpected events support the referential coding account not only for JSE-like effects, but also for the JSE where a Simon task is shared between two humans. Referential coding can therefore be considered as a valid explanation for the JSE and joint action when the same or different tasks are shared between human actors.

Acknowledgments The present research was financially supported by the German Research Foundation Grants DFG LI 2115/1-1; 1-3 awarded to R. L. We would like to thank Kerstin Dittrich, Barbara Müller and two anonymous reviewers for their helpful comments on an earlier version of this article.

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