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ORIGINAL ARTICLE

Does the anticipation of compatible partner reactions facilitate action planning in joint tasks?

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Abstract Observing another human's actions influences action planning, but what about merely anticipating them? In joint action settings where a partner's subsequent actions are a consequence of one's own actions, such contingent partner reactions can be regarded as action effects. Therefore, just like automatic effects they might facilitate those of a person's actions that overlap with them in relevant features. In Experiments 1 and 2, the spatial compatibility of contingent partner reactions was manipulated and compared with the influence of automatic effects. Experiment 1 used a simplistic scenario in which lateral keypress actions by the subject were responded to by mouse movements of a partner producing spatially compatible or incompatible visual effects. Experiment 2 transferred the paradigm to a more complex task in which subjects manually relocated virtual objects on a multi-touch display, and these or other objects were subsequently manipulated by the partner. In Experiment 1, compatible partner reactions speeded up subjects' preceding actions, whereas in Experiment 2 the influence was not statistically reliable. To test whether influences of partner reaction compatibility could be found in such naturalistic settings at all, Experiment 3 also used a multi-touch setting but varied temporal instead of spatial compatibility, which has several methodological advantages. This time, a compatibility effect emerged in subjects' movement initiation times, whereas contrast effects were found for movement durations. These findings indicate that the principles of ideomotor action control can be extended to joint action settings. At the same time, they also emphasize the importance of task features in determining whether our own behaviour is influenced by anticipations of another person's reactions.

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Introduction

In joint tasks, humans can easily coordinate their behaviours with each other. But what are the basic processes that enable such coordination? One important factor is that merely observing the actions of others can influence a person's own action planning. For instance, it is easier to select an action when seeing someone else performing the same action versus a different action (e.g. Bertenthal, Longo, & Kosobud, 2006; Brass, Bekkering, & Prinz, 2001; Stürmer, Aschersleben, & Prinz, 2000). Action observation tends to activate similar representations in the observer's mind, resulting in a visuomotor priming of corresponding motor programmes. However, when jointly performing tasks with a partner, his actions are not merely a stimulus that suddenly appears and exerts an influence on our behaviour. Instead, the partner's actions are usually predictable to some degree, which is at least partly due to the fact that they depend on what we have done just before. Such mutual dependencies could play a functional role in our own action planning, because they enable anticipations of the partner's reactions, which may in turn guide action selection. Before outlining the rationale of the present study, evidence will be presented on the influences of experiencing contingent partner reactions and the role of anticipated action effects for action control processes.

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Influences of a partner's contingent reactions

Compared to myriads of studies dealing with the automatic imitation of observed actions, there is only a small amount of research in the opposite direction, investigating how we are affected by other people's reactions to our actions. Most of this work has studied the prosocial effects of being imitated. People tend to like the imitator more (Chartrand & Bargh, 1999), behave in more generous and helpful ways (Van Baaren, Holland, Kawakami, & Van Knippenberg, 2004) and even empathize with another person's pain more strongly than when this person is performing non-matching actions (De Coster, Verschuere, Goubert, Tsakiris, & Brass, 2013). Moreover, being imitated seems to be pleasurable, as indicated by an activation of reward circuits in the brain when subjects watched videos that created an impression of being imitated (Kühn et al., 2010).

These studies demonstrate that another person's contingent reactions to our own actions affect our evaluations, but little is known about their influences on action control processes. There is theoretical reason to believe that such influences could exist. In many joint action scenarios, the actions of one partner will be determined by the preceding actions of the other one. For instance, if a person places a glass of water on the table in front of a partner, the partner will pick it up at the very place where the person has put it, instead of anywhere else. Accordingly, in situations in which this action–reaction link is sufficiently strong, the reactions can be conceived of as predictable action effects.

Ideomotor theory and anticipation in joint action

Action effects play a crucial role in the planning of actions, as has been demonstrated in the literature on ideomotor action control (for an overview see Hommel, 2013; Hommel, Müsseler, Aschersleben, & Prinz, 2001). According to ideomotor theory, actions are selected by mentally representing their sensory consequences, which in turn directly activates the associated motor programmes. For instance, if a button press always switches on a lamp, merely seeing or imagining a lamp lighting up will facilitate actions such as the button press, because bi-directional associations between the action and its effect have been formed. Consequently, effects that have contingently followed an action can subsequently serve as retrieval cues and thus facilitate performance (Elsner & Hommel, 2001).

Evidence for a direct influence of mere effect *anticipations* on action control stems from the response–effect compatibility paradigm (Kunde, 2001). In this paradigm, actions are followed by either compatible or incompatible effects, i.e. effects that do or do not overlap with the action in a relevant feature such as location (Kunde, 2001; Pfister, Janczyk, Wirth, Dignath, & Kunde, 2014), duration (Kunde, 2003) or intensity (Kunde, Koch, & Hoffmann, 2004). Typically, actions can be initiated faster when they produce compatible effects, which must be a result of anticipation as the effect only occurs after the action.

Such direct influences of perceptions and mental representations on action control can be explained by common coding accounts (Hommel et al., 2001; Prinz, 1997), assuming that perception and action operate on the same cognitive codes. Thus, when these codes are activated by mentally representing an event with certain features, activation will spread to motor actions that share these features. Common coding accounts have been applied to explain the findings of automatic imitation presented above (e.g. Stürmer et al., 2000) and provide a promising framework for joint action research (for an overview see Loehr, Sebanz, & Knoblich, 2013). This is because the close links between perception and action enable joint action partners to match their partners' actions, as the required codes have already been activated by their perception. Moreover, it allows participants to use their own motor repertoire for simulating and predicting their partners' upcoming actions and their consequences (Wolpert, Doya, & Kawato, 2003), which in turn facilitates the performance of appropriate reactions. Given the importance of these mechanisms for joint action, it is surprising that action effect anticipation as a hallmark of common coding and ideomotor theory has hardly been studied in the joint action literature.

A partner's predictable reactions to our own actions could serve a function similar to that of anticipated action effects, priming those actions that typically trigger them. To investigate this impact of another agent's reactions, some studies have used virtual others as action effects in response–effect compatibility paradigms (Kunde, 2001). These studies indicate that it is easier to produce a smile when knowing that it will result in the presentation of a smiling face rather than a frowning face (Kunde, Lozo, & Neumann, 2011), and people are faster to initiate a simulated handshake when it will be followed by a spatially compatible hand image (Flach, Press, Badets, & Heyes, 2010). Even less voluntarily controlled actions such as saccades to faces can be influenced by social action effect anticipations: when subjects knew that their gaze would turn an image of a neutral face into a smile, their saccade landing positions were biased towards the mouth region, whereas the expectation of a frown biased saccades towards the eye region (Herwig & Horstmann, 2011).

Whereas these studies provide evidence for effect anticipations with social stimuli, they do not allow drawing conclusions about joint action settings involving two real humans. To do this, there are two necessary conditions. First, people need to be capable of anticipating the actions of others in general. This is not a trivial ability, given that human actions largely depend on intentions and internal states, which make them less predictable than physical events. Nevertheless, anticipation is a core mechanism in observing and understanding other people's actions. On a neuronal level, action simulation is of anticipatory nature (Chaminade, Meary, Orliaguet, & Decety, 2001; Nishitani & Hari, 2000; Ramnani & Miall, 2004). Behaviourally, action anticipation is reflected in the predictive eye movements made by observers of object-directed actions (Flanagan & Johansson, 2003; Rotman, Troje, Johansson, & Flanagan, 2006) and their ability to predict temporally occluded actions (Graf et al., 2007; Sparenberg, Springer, & Prinz, 2012). Observers' predictive abilities depend on the actions they are generally capable of (Aglioti, Cesari, Romani, & Urgesi, 2008) or currently performing (Springer et al., 2011). For instance, observers of grasping actions make faster anticipatory saccades to a target object when they are holding an object of similar size in their hand (Costantini, Ambrosini, & Sinigaglia, 2012). However, in contrast to the accumulating knowledge about the influence of observers' actions on their action anticipations, much less is known about the consequences of such anticipations for an observer's own actions.

A second condition for a transfer of action effect anticipations to the domain of joint action is that people should be able to anticipate others' actions on the basis of their *own* preceding actions. Only if they are able to do so, their actions can benefit from evoking compatible partner reactions. For instance, when performing a duet, a musician should be able to predict how the partner will respond to his current way of playing, instead of only knowing the partner's piece of the melody. If the musician is able to form such predictions, he is likely to benefit from anticipating tones that match his own performance, whereas expecting dissonant tones might be detrimental. Indeed, there is first evidence for such anticipatory mechanisms when two people act together. Pfister, Dignath, Hommel, & Kunde (2013) asked subjects to perform button presses of particular durations and, subsequently, a partner performed a temporally compatible or incompatible reaction, pressing a button with either the same or a different duration. Compatible partner reactions reduced the initiation times of subjects' actions, indicating that a real human partner's forthcoming reactions to one's own actions are considered during action planning. However, as the study used relatively arbitrary actions that were not embedded in a joint task, it remains to be investigated to what degree the ideomotor principle can be transferred to more naturalistic joint action settings.

Open questions: the compatibility of contingent partner reactions in joint tasks

The goal of the present study was to test in what way a partner's contingent reactions to one's own actions (henceforth CPR) are considered during action planning in joint tasks. Two aspects of this question were investigated in the present research: whether the influence of CPR is comparable to that of automatic action effects and whether it is restricted to simplistic paradigms or can also emerge in more naturalistic joint tasks.

Concerning the first aspect, it is not yet clear whether the influence of CPR compatibility differs from that of automatic action effects, such as a lamp lighting up when a button is pressed. Although there is some evidence for compatibility effects with virtual partner reactions (Flach et al., 2010; Herwig & Horstmann, 2011; Kunde et al., 2011) and one study with real human reactions (Pfister et al., 2013), no previous studies have compared CPR with automatic action effects. Investigating the similarity between these two types of effects is important as it speaks of the interdependence between two people's actions in joint action contexts. On one hand, being influenced by what we expect the partner to do could be quite helpful in fine-tuning coordination. On the other hand, given the diversity in people's abilities and motives, it would certainly not be adaptive to depend on another person's reactions too strongly while performing goal-directed everyday tasks and thus being seriously impaired whenever these reactions differ from our actions. Therefore, the present study tested whether the size of compatibility influences depended on whether they were generated by a computer or a partner.

A second factor that needs to be considered when investigating the influence of CPR is the complexity of the interactive task. If CPR can indeed influence a person's actions, is this restricted to closely controlled scenarios in which the partner is performing very precise and uniform reactions such as button presses that are temporally locked to the actions preceding them, or do such influences persist when two people engage in a more naturalistic task, allowing for some degrees of freedom in action execution and being embedded in the context of goal-directed, joint object manipulations?

Three experiments were conducted to address these questions. In the first two experiments, the spatial relationships between a subject's actions and a partner's subsequent reactions were manipulated, resulting in either spatially compatible or incompatible CPR, whereas in the third experiment temporal compatibility was varied. Experiment 1 used a simplistic scenario. It aimed at replicating findings from the spatial response–effect compatibility paradigm introduced by Kunde (2001), which were transferred to a setting in which action effects were produced either by the computer or by a human partner. The goal of Experiment 2 was to test whether the findings from Experiment 1 generalize to more naturalistic settings. Therefore, a joint task was used in which participants had to manually relocate and manipulate virtual objects together on a multi-touch display. Finally, Experiment 3 was similarly naturalistic as Experiment 2, but had varied temporal instead of spatial compatibility by requiring participants to perform either fast or slow swipe gestures on virtual objects.

There are several ways in which the present study differs from that of Pfister et al. (2013), where subjects pressed buttons and were either imitated or counter-imitated. For instance, the actions performed by the two participants in Experiments 1 and 2 were quite different from each other and only overlapped in their spatial end point. Until now, it is not clear whether such non-imitative reactions of others can influence action planning. Furthermore, Experiments 2 and 3 used actions that were rather complex, both physically and in terms of being embedded in a goal-directed task. This may change the subject's attention to the partner's reactions, a topic that will be discussed in more detail below.

Experiment 1

The first experiment varied spatial compatibility in a simplistic task. Using spatial compatibility as a method allows for a straightforward comparison between CPR and automatic, computer-generated effects. This is because the relevant aspect of the action effect (e.g. changing the colour of a particular location) can be held constant across conditions, which would be more difficult when using other dimensions such as the duration or type of a partner's gesture. The experiment aimed at testing whether spatial CPR compatibility can affect action planning at all and whether this differs from the influence of automatic effects.

There are two reasons to suspect such differences. First, another person cannot possibly act as uniformly and thus predictably as a machine. For example, if you press a light switch, the light will turn on immediately or with a constant temporal delay. Instead, if you offer someone a glass of water, he might take it in one of several possible ways (differing for example in grasp location, force or direction) and only after some more or less predictable amount of time. Thus, whereas automatic effects are rather stable in their spatial and temporal parameters, CPR are not. Human co-actors might even produce occasional errors when performing their reactions, reducing the contingency with the subject's actions. Critically, the learning of action effect associations depends on the co-occurrence of both events within a brief time period and a high contingency (Elsner & Hommel, 2004). For that reason, it is unclear whether the inevitable variability of human co-actors will allow for a formation of stable, bi-directional associations between CPR and the actions that trigger them.

A second reason to put the impact of CPR anticipations into doubt is their causation: although they are to some degree determined by the subject's actions and seem to be processed in a similar way to directly caused events (as reflected in measures of intentional binding, Pfister, Obhi, Rieger, & Wenke, 2014), the subject's action is not the immediate cause of the effect. Previous research suggests that a conscious inference of causality is not a necessary condition for action–effect associations to emerge (Verschoor, Eenshuistra, Kray, Biro, & Hommel, 2011), and sometimes participants are not even aware of these causal relations. Still, previous studies did not investigate the modulation of actions by effects that are only contingent but explicitly lack a causal link with the action.

Despite these reasons to put the formation of stable and functional action–CPR links into question, there are also reasons to assume that CPR might exert a particularly strong influence. As their social nature may make them rather salient, they might even be more effective than automatic effects. This possibility is supported by studies investigating the differences in automatic imitation of human versus machine actions. Even when both types of observed movement stimuli are task irrelevant and physical stimulus parameters are held constant, movements that are believed to be caused by a human exert a stronger influence on the observer's own movements (Liepelt & Brass, 2010; Longo & Bertenthal, 2009; Stanley, Gowen, & Miall, 2007). Similarly, CPR might be attended more closely than irrelevant automatic effects, leading to a stronger integration with the subject's own action representations.

Taken together, Experiment 1 had two goals. First, it attempted a replication of the basic action effect compatibility phenomenon, but with CPR serving as compatible or incompatible action effects. Second, it was to be tested whether any differences would emerge between the influences of CPR and automatic effects. The spatial response–effect compatibility paradigm by Kunde (2001) was adapted to a joint action setting. Subjects had to respond to colour stimuli with four keypresses, each of them triggering a visual effect at a location that did or did not match the respective finger position. In a control condition, these effects appeared automatically after the person's action, whereas in the joint condition they were produced by a partner moving his mouse cursor to the effect location once he had perceived the subject's response.

The use of different response modalities for the two participants (i.e. keyboard/pressing vs. mouse/dragging) made their specific motor actions quite different from each other. This is in contrast with studies of automatic imitation in which subjects typically perform actions that are identical to the observed actions (for an overview of the action modalities used in such studies, see Heyes, 2013). However, in the present experiment, the use of different response modalities was necessary. On the one hand, the subject needed to press buttons to achieve a close replication of the original spatial response–effect compatibility paradigm (Kunde, 2001). At the same time, if the partner had also performed button presses, the CPR would have been almost impossible to perceive for the subject, or only via their final remote consequence (i.e. the effect position lighting up). Conversely, when using mouse cursor movements, the entire action process can be observed, which might also give the CPR a more human-made impression. Moreover, while the non-identical nature of actions and CPR distinguishes Experiment 1 from studies of automatic imitation, in response–effect compatibility paradigms it is even the norm that actions are different from their effects. For instance, pressing a button is not directly comparable to the appearance of a tone or visual effect stimulus, and the two events only match by way of sharing certain features (e.g. location or intensity). While a high degree of dimensional overlap is beneficial for response–effect compatibility influences to emerge (Janczyk, Yamaguchi, Proctor, & Pfister, 2015), a full overlap is not required. Therefore, it is hypothesized that CPR compatibility benefits will be observable despite the two participants' actions being non-identical. That is, besides an overall compatibility benefit, planned comparisons should reveal shorter reaction times for compatible than incompatible blocks in the partner condition.

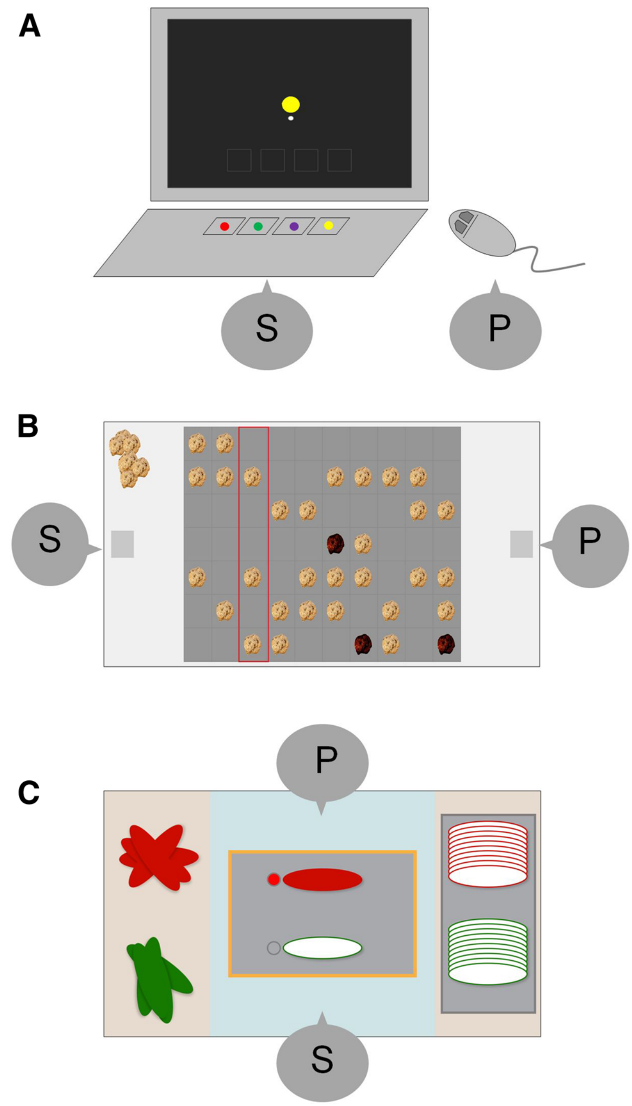

Fig. 1 Stimuli and setup for all three experiments. **a** In Experiment 1, the subject and partner sat next to each other in front of a computer screen, with the subject operating the keyboard and the partner operating the mouse. **b** In Experiment 2, both participants performed hand gestures on a multi-touch monitor. The *red frame* highlights the row relevant in a given trial, and the *dark brown* cookies are those that have already been coloured by the partner. **c** In Experiment 3, the subject and partner took turns in colouring virtual objects with swipe gestures. The figure depicts a situation in which the subject has just completed his move and the partner can start reacting. *S* subject, *P* partner (colour figure online)

Methods

Subjects

Twenty-four students of the Technische Universität Dresden (13 female) in the age range of 19–46 years ($M = 26.1$, $SD = 5.5$) participated in the study in exchange for course credit or a payment of 5€ per hour. The experimenter and author of this study (RM) acted as the partner for all subjects.

Apparatus and stimuli

The experiment was conducted on a standard PC, with the subject operating the keyboard and the partner operating the mouse. Stimuli were presented on a CRT display with a resolution of 1024 by 768 pixels at a refresh rate of 100 Hz. A coloured dot (red, green, violet or yellow) with a diameter of 50 pixels was presented in the centre of the screen on a dark grey background. At the lower edge of the screen there were four horizontally aligned, empty squares (*effect boxes*) of 100 × 100 pixels each and with a distance of 40 pixels between them. These boxes remained visible throughout the trial, and visual action effects were realized by one of them turning white. A standard QWERTZ computer keyboard was placed below the monitor, so that the effect boxes were located directly above the 1, 4, 7 and 0 keys, which served as response keys for the dot colour discrimination task and were operated by the middle and index fingers of the subjects' left and right hand. The partner's mouse cursor was presented as a white dot with a diameter of 20 pixels. At the beginning of each trial, it was automatically repositioned to the horizontal centre of the screen, but vertically shifted to 66 pixels below the stimulus dot. For an overview of the experimental setup, see Fig. 1a.

Procedure

The experiment consisted of four blocks of 152 trials, with each block representing a combination of compatibility (compatible, incompatible) and effect type (partner, automatic). Effect type was varied between the first and second part of the experiment, with half of the subjects starting with partner-generated and half with automatic effects, respectively. The order of the compatibility conditions was counterbalanced across participants. Thus, there were four types of block order, each being performed by one-fourth of the subjects (P_cP_i A_cA_i, P_iP_c A_iA_c, A_cA_i P_cP_i, A_iA_c P_iP_c, with P, A, c and i denoting "partner", "automatic", "compatible" and "incompatible", respectively). Before the actual experiment, subjects performed eight practice trials in which no action effects were presented. Each experimental trial started with a fixation cross that remained visible for 500 ms and was followed by the presentation of the coloured dot stimulus. Colours were chosen randomly, but with the constraint that each colour appeared equally often during a block. The stimulus colour signalled the correct key, and subjects were instructed to respond as quickly and accurately as possible by pressing one of the four keys. In case of an error, subjects received error feedback, with the German word for error appearing on the screen immediately after pressing the key and remaining for 2000 ms, after which the trial was aborted. In correct trials, the keypress was followed by a visual action effect, i.e. the filling of one of the four effect boxes, which remained visible on the screen for 300 ms, and then the next trial started.

In the partner condition, the partner who was seated on the subject's right side started moving the mouse towards an effect box as soon as the subject had submitted a keypress. The effect box was filled once the partner's mouse cursor had reached it. Only the correct box in a given trial was activated, to make sure that if the partner erroneously moved his mouse to a wrong box, no effect appeared until the move was corrected. In the automatic condition, the subject's keypress directly triggered the filling of a response box without any temporal delay. The partner remained present but did not touch his mouse, to keep the impact of social facilitation constant across experimental conditions.

Compatible effects consisted of a filling of the effect box that was located directly above the pressed key, whereas in incompatible trials the box was coloured that was replaced from the pressed key by two positions. Thus, incompatible effects were as predictable as compatible effects, to avoid confounding the influences of compatibility and predictability. The issue of compatibility versus predictability will be specifically addressed in Experiment 3.

Results

Reaction times

The first trial in a block, responses longer than 2000 ms, erroneous responses and trials following an error were excluded (7.9 % of the data). The remaining data were subjected to a repeated measures ANOVA with the factors' compatibility (compatible, incompatible) and effect type (partner, automatic). There was a main effect of compatibility, $F(1,23) = 7.047$, $p = 0.014$, $\eta_p^2 = 0.236$, a main effect of effect type, $F(1,23) = 13.592$, $p < 0.001$, $\eta_p^2 = 0.371$, but no interaction between both factors, $F < 1$. Reactions were faster with compatible than with incompatible action effects (705 vs. 725 ms), and subjects responded more quickly when performing the task with the partner (697 vs. 734 ms). Planned comparisons revealed that the compatibility benefit was significant for partner-generated effects, $p = 0.041$ (see Table 1).

The absence of an interaction suggests that the influence of compatibility does not differ between automatic and partner-generated effects. However, as it is not statistically

Table 1 Means and standard deviations of the reaction times and movement durations (in ms) for partner-generated and automatic compatible and incompatible responses in Experiments 1 and 2

	Experiment 1		Experiment 2	
	Mean keypress RT	SD	Mean movement time	SD
Partner				
Compatible	687	93	2074	380
Incompatible	706	105	2151	402
Automatic				
Compatible	724	101	2018	264
Incompatible	745	117	2110	249

possible to infer the null hypothesis from the absence of significance, the data were re-analysed using Bayes factors (Rouder, Speckman, Sun, Morey, & Iverson, 2009). This procedure allows for a direct comparison of the null and the alternative hypothesis given the present data, based on a likelihood ratio of both hypotheses. For the F value of the interaction between compatibility and effect type, the corresponding t value was 0.139, and at a sample size of $N = 24$ the JSZ Bayes factor for this contrast was $B_{01} = 4.62$. Thus, the null hypothesis was 4.62 times more likely than the alternative, which according to the classification by Raftery (1995) constitutes positive evidence that the partner and automatic conditions did not differ in the compatibility effects they produced.

A possible explanation for the similar compatibility benefits emerging with both effect types is that there might have been transfer effects from the automatic condition to the partner condition. In this case, there should be an interaction with the order of the effect types (partner first vs. automatic first): compatibility effects in the partner condition should be larger when performed after the automatic condition than before it. Therefore, the reaction time analysis was repeated with order as an additional between-subjects factor. However, there were no significant interactions involving order and compatibility, both Fs < 3 and both ps > 0.1.

It has been reported that influences of effect compatibility are larger or sometimes even restricted to relatively slow responses (Kunde, 2001; Kunde et al., 2011; Pfister et al., 2013), presumably because anticipated effect representations need time to build up. To test this within the present data, the reaction times for each subject and experimental condition were split into five quintiles according to their duration, with each quintile containing an equal number of trials. The factor quintile was included in the ANOVA, from which only the interactions including bin and effect type will be reported to avoid redundancy. The interaction of compatibility and bin missed significance, $F(4,92) = 2.282$, $p = 0.066$, $\eta_p^2 = 0.090$. Reliable compatibility effects were only present in the third and fourth bins, both ps < 0.004, and not in any of the other bins, all ps > 0.05. There was no triple interaction with effect type, $F(4,92) = 1.423$, $p = 0.233$, $\eta_p^2 = 0.058$, indicating that the dependency of compatibility effects on reaction time was similar for automatic and partner-generated effects (see Fig. 2).

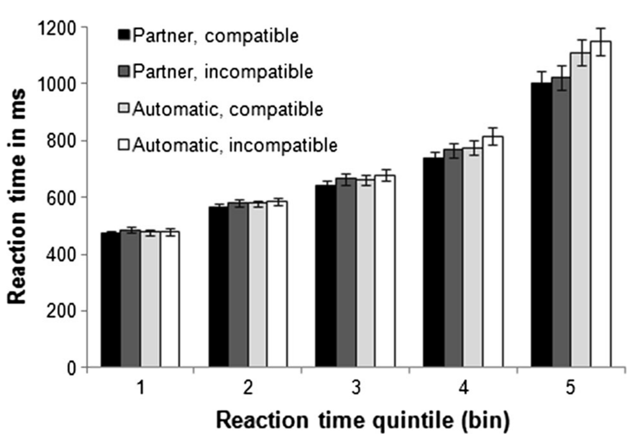

Fig. 2 Reaction time distribution in Experiment 1. *Error bars* represent standard errors of the mean

Mouse movements of the partner and their relation to subjects' reaction times

To control for differences in parameters of the partner's reactions, the partner effect latency (i.e. time between the subject pressing a key and the partner landing on the corresponding effect box with his cursor) was compared between compatibility conditions. There was a significant difference, $t(23) = 3.539$, $p = 0.002$, indicating that partners responded more quickly in compatible than incompatible blocks (560 vs. 614 ms).

As explained in the introduction, one possible obstacle for CPR compatibility effects to emerge is that CPR do not follow the action as quickly and consistently as automatic effects do. Therefore, it is possible that the compatibility effect will vary with the characteristics of the CPR, being stronger for subjects who experienced temporally closer and/or more consistent CPR. To test this possibility, the partner effect latency was correlated with the compatibility effect, i.e. the difference between mean reaction times in compatible versus incompatible blocks for each subject. If longer effect latencies attenuated compatibility influences, a negative correlation would be expected. Instead, there was only a non-significant positive correlation, $r = 0.147$, $p = 0.492$. Additionally, the partner's compatibility effect was correlated with that of the subject, and this correlation was not significant either, $r = 0.133$, $p = 0.536$ (see Fig. 3a).

Similarly, besides the absolute time that the partner needed for his response, the higher temporal variability of CPR could distinguish them from automatic effects. However, when correlating the standard deviations of the partner's effect latency with subjects' reaction times, again no significant correlation was found, $r = -0.044$, $p = 0.839$. Thus, the present data do not support the notion that an increased delay or variability of CPR reduces their influence.

Error rates

Overall, subjects committed errors in 3.0 % of the trials. A repeated measures ANOVA with the factors compatibility

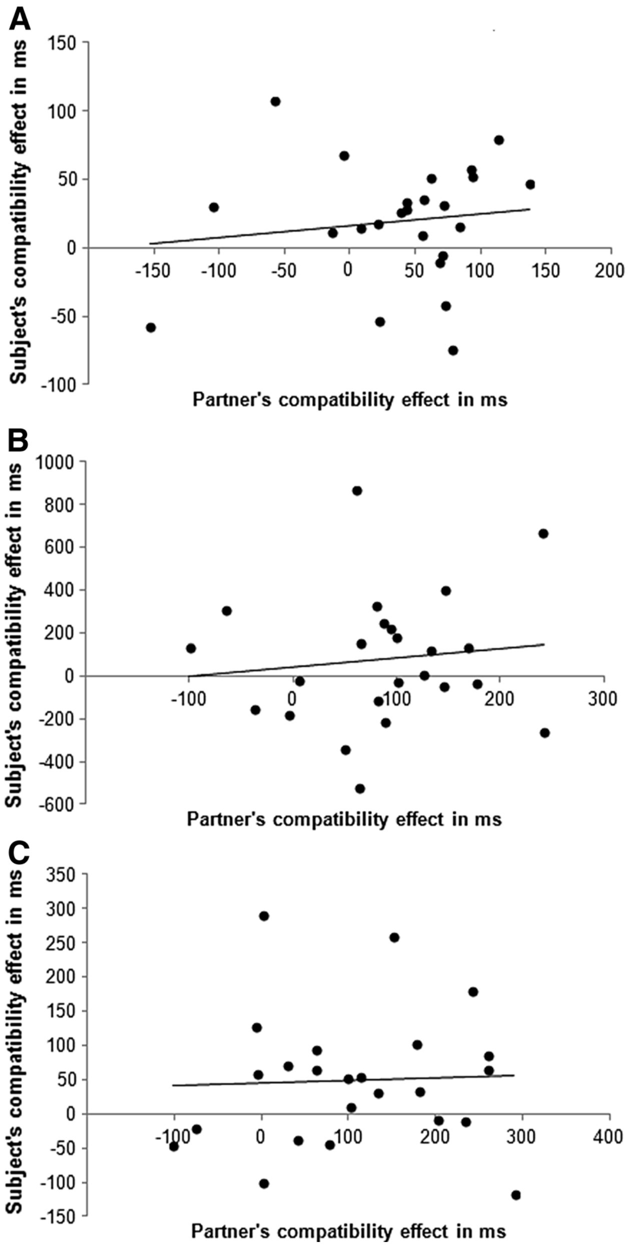

Fig. 3 Correlation of the subject's compatibility effect and the partner's compatibility effect in Experiment 1 (**a**), Experiment 2 (**b**) and Experiment 3 (**c**)

and effect type revealed that the main effect of compatibility missed significance, $F(1,23) = 3.895$, $p = 0.061$, $\eta_p^2 = 0.145$, that there was a highly significant main effect of effect type $F(1,23) = 12.540$, $p = 0.002$, $\eta_p^2 = 0.353$, and again no interaction, $F < 1$. Subjects committed fewer errors in the presence of a partner (2.6 vs. 3.4 %). Although numerically, errors were less frequent in compatible than incompatible blocks (2.7 vs. 3.2 %), this difference was not statistically reliable, and planned comparisons revealed that the compatibility was non-significant in the partner condition, $p > 0.2$.

Discussion

The purpose of Experiment 1 was to test whether a partner's contingent reactions to a subject's actions (CPR) are anticipated during the planning of the action, thereby facilitating the selection of actions that share relevant features with this reaction. In a social version of the spatial response–effect compatibility paradigm (Kunde, 2001), a subject's keypress responses to colour stimuli were followed by spatially matching versus non-matching visual effects which were either produced by the computer or by a partner's mouse movements to the respective effect locations. Reaction times were shorter in blocks with compatible effects, irrespective of whether these effects were produced automatically or by the partner.

The compatibility benefit depended neither on the latency of the CPR nor on the variability of this latency. This indicates that response priming by (social) effect anticipations is not restricted to situations in which the partner's reactions occur in a high temporal proximity to the subject's actions or at a consistent delay. Note, however, that the mean temporal delay of CPR in this study was in a range of about 300–1300 ms, which does not allow for an extrapolation from the present findings to situations in which the partner's reaction occurs at much larger delays in the range of several seconds or minutes, let alone days.

The compatibility effect was statistically reliable only for relatively slow reactions, replicating previous results (Kunde, 2001). In the present study, it did not reach significance in the slowest quintile, but numerically it was largest there, indicating that the high variance of very slow responses might have been responsible for the lack of a compatibility benefit in this particular condition. The dependence on response speed suggests that an anticipation of action effects, in general, and CPR, in particular, needs time to build up (cf. Kunde, 2001).

Overall, reactions were faster and error rates were lower when the effects were generated by a partner. Presumably, this can be ascribed to a general effect of social facilitation and is in line with other joint action studies that reported faster responding when performing tasks with active co-actors (e.g. Atmaca, Sebanz, & Knoblich, 2011; Pfister, Dolk, Prinz, & Kunde, 2014). However, as effect type did not interact with compatibility in the present study, the general speed advantage in the partner condition is not relevant for current purposes.

Three conclusions can be drawn from Experiment 1. First, spatial CPR can prime responses just like automatic action effects. Second, this influence does not vary with the temporal delay or variability of the CPR. Third, just like automatic effects, CPR influence short responses to a lesser degree, reflecting the time course of activating mental representations of an action's consequences. Thus, the basic phenomena from response–effect compatibility paradigms can be replicated when the effects are generated by a partner, despite this partner reacting more slowly and less consistently than a computer.

Experiment 2

In Experiment 1, the CPR were arbitrary reactions to the subject's actions—basically, the partner acted as a human light switch. Neither were the subject's actions and the partner's reactions embedded in the context of a joint task, nor did they serve any meaningful (shared) goal. Such simplification is quite common in studies of automatic imitation, where subjects typically observe non-transitive movements such as the lifting of fingers and are asked to perform similar versus different movements in response to an unrelated, imperative stimulus (for reviews see Gowen & Poliakoff, 2012; Heyes, 2013). That is, the observed action is performed for the mere sake of triggering imitation, instead of representing a purposeful action. Such arbitrariness has notable advantages in terms of experimental control, but it can influence the way in which observers process the actions they see.

For example, the mirror neuron system is differentially activated depending on the action context and is more active when observed actions are performed in a visual context that indicates a particular goal than when the same actions are performed without context (Iacoboni et al., 2005). Similarly, goal- or object-directed actions produce higher amounts of motor interference on an observer's own actions than non-transitive actions (Bouquet, Shipley, Capa, & Marshall, 2011). This suggests that an inference of intentions behind another person's actions increases their impact on the observer's own actions. Thus, merely anticipated CPR might affect action planning more strongly when they are perceived as goal directed. This assumption is also supported indirectly by the finding that effect compatibility speeds up responses more strongly—or sometimes even exclusively—when the effects are task relevant (Ansorge, 2002). On the other hand, it is possible that goal-directedness even decreases the impact of CPR, because it might put subjects' focus on the object manipulation task to a stronger degree and away from the partner's particular actions which are only a means of completing that task. Therefore, it should be investigated whether CPR compatibility can be effective in conditions where it is not the primary focus, but "just happens" while the partner is engaged in his own purposeful activities during the performance of a goal-directed joint task.

A second and related limitation of Experiment 1 is that there was no meaningful interaction between both participants. The dependency between the subject's actions and the partner's reactions was predefined, but arbitrary in its nature. There is no functional reason why pressing a key should trigger the filling of a box. These two actions were related in terms of their physical properties (i.e. location), but not in any semantic way such as being two component actions within a joint task. Therefore, based on the results of Experiment 1, one cannot tell whether CPR can exert an influence on a person's preceding actions in more interactive scenarios. To overcome these shortcomings, the following requirements were defined for Experiment 2.

Most importantly, the compatibility was not to occur as a deliberate imitation, but as a functional step within a goal-directed object manipulation task. To clarify, to investigate the influence of CPR, there needs to be a clear dependency between CPR and the subject's preceding actions. Thus, in terms of the interaction structure, nothing was changed relative to Experiment 1: the subject's actions still triggered predictably compatible or incompatible reactions by the partner. However, the focus should not be on the CPR's compatibility per se, but on the content of this reaction.

Besides the embedding of actions in an object-centred task, the visual component of the CPR needs to be considered. Experiment 1 revealed no differences in the compatibility effects produced by partner-generated and automatic effects. However, to test whether there is something special about the influence of human reactions, CPR should be made more distinct and "typically human". Therefore, a task is needed in which the human co-actor does not only serve the function of a poorly reliable computer, reacting with hardly perceivable movements to produce a visible effect in the environment. Instead, subjects should actually see another human performing motor actions. At the same time, to enable a comparison of both effect types, their ultimate consequence should remain the same, but it needs to be caused in a different way.

To meet these requirements, Experiment 2 used a more naturalistic joint task in which subjects moved virtual cookies to pre-specified locations on a multi-touch table. A colour cue indicated the vertical and horizontal target position on a board, and the subject was required to drag the cookie there. Once the cookie was placed, the partner performed a swipe gesture on either the same or a different cookie to colour it dark brown, as if he was icing it with chocolate. If in this scenario a partner's spatially compatible reactions facilitate action planning, the initiation times and total durations of the subject's hand movements should be reduced when subjects can anticipate the partner to colour the same cookie. No effects on error rates were expected, because performing continuous, temporally extended hand movements allows for corrections during the course of the movement and thus makes errors highly unlikely.

Note that the step from Experiment 1 to Experiment 2 is quite ambitious. In that sense, Experiment 2 can be considered as a form of testing the limits for the conditions under which CPR compatibility influences can still be observed. This is because the use of large and relatively complex actions adds a high degree of variability and this might hinder the emergence of CPR compatibility effects. Experiment 2 thus provides a test of how natural one can get without washing away the effects of CPR representations on performance. This is particularly uncertain, however, as influences of a partner's actions tend to be of relatively modest size (cf. Pfister, Dolk et al., 2014). However, the practical relevance of CPR compatibility effects in the laboratory can be seriously questioned if they do not generalize to more realistic scenarios. Also, if they are absent in such complex paradigms, later experiments can be specifically designed to test the reasons for their absence and the conditions under which they do occur. Therefore, testing the limits is certainly warranted.

In a control condition, the partner performed no actions and the colouring of either the same or a different cookie was done by the computer. In contrast to the effects used in Experiment 1, the CPR and computer effects used in Experiment 2 were visually quite distinct. This is because another person's hand movements are more salient than the subtle movements of a small mouse cursor in terms of their amplitude, the involvement of the partner's body and their potential of being directly mapped to the subject's own motor repertoire. Thus, the difference between CPR and automatic effects might be more obvious. As both types of effects still had identical end states, it is interesting whether they will have similar consequences despite the differences in their visual appearance. In this case, a replication of the previous findings is expected as reflected in the absence of an interaction between compatibility and effect type. If they are perceived as very different, there are two possible outcomes. On the one hand, CPR could produce stronger compatibility effects, which might be expected for example as a consequence of their social nature, the presence of a joint goal or their increased visual salience. On the other hand, CPR are more temporally removed from the subject's action, less uniform and contain information about presumably irrelevant early stages of the movement. This could result in a reduction of the compatibility effect relative to automatic effects. Again, planned comparisons will test whether there is a difference between compatible and incompatible blocks in the partner condition.

Methods

Subjects

Twenty-four students of the Technische Universität Dresden (14 female), aged 19–34 years ($M = 24.6$, $SD = 3.9$), participated in the study and received course credit or a payment of 5€ per hour. The experimenter acted as the partner for all subjects.

Apparatus and stimuli

The experiment was performed on a M2256PW multi-touch monitor (3M) with a display size of 22″ and a spatial resolution of 1280 × 800 pixels. The display of the monitor was rotated horizontally, forming a table that served as the shared workspace. On the subject's side of the table, there was a pile of ten oval virtual cookies with a size of 78 × 104 pixels each. In the centre of the table there was a grey board of 980 × 1010 pixels, consisting of a grid structure with ten rows and seven columns, so that each field subtended an area of 98 × 144 pixels. The rows corresponded to the trials within a miniblock (see below) and the columns constituted the target positions. Three of the seven fields in each row were already occupied by a cookie (see Fig. 1b). Their positions were chosen pseudo-randomly with the only restriction being that there always had to be a cookie two positions adjacent to the target gap (left or right, depending on the number of the target gap). This was the location in which the incompatible effects appeared, ensuring that that compatible and incompatible effects were equally predictable. Visual effects consisted of one cookie being coloured dark brown after the subject had placed his cookie at the target position. Within each trial, the correct one of the four gaps was indicated by the colour of a frame surrounding the current row (red, green, violet and yellow for gaps 1–4, respectively). A grey rectangular field of 100 × 120 pixels, positioned 30 pixels away from the edge of the table in front of each person, served as the starting position for the movements.

Procedure

The experiment consisted of four blocks corresponding to the combinations of compatibility (compatible, incompatible) and effect type (partner, automatic). Effect type was varied between the first and the second part of the experiment, with half of the subjects starting with partner-generated and half with automatic effects, respectively. The order of the compatibility conditions was counterbalanced across participants. Each block consisted of ten miniblocks (boards) with ten trials each. Thus, there were 100 trials per condition and 400 trials in total. Before the experiment, subjects performed one miniblock of practice, in which no visual effects appeared.

The subject and the partner were standing at opposite sides of the multi-touch table.[1] Before each trial, the

[1] The relative spatial positioning of the participants differed between the experiments (next to each other vs. opposite sides). This resulted from the different affordances posed by the technologies (standard computer monitor vs. multi-touch table) and thus was mainly due to practical considerations. However, note that whereas the position of the participants' bodies differed, the position and movement direction of their spatial indicator (i.e. mouse cursor in Experiment 1 and index finger in Experiment 2) were identical.

subject had to take one cookie from the pile, drag it to his starting position and then briefly let go of it, which made the cookie snap to a fixed place at the centre of the starting position. To start a trial, the subject had to put his right index finger on the cookie. This triggered a presentation of the cue indicating the target position—a coloured frame surrounding the currently relevant row—after a delay of 500 ms. The frame colour indicated the correct one of the four empty spaces (gaps) in the row. Target gaps and thus colours were chosen randomly, with the only restriction being that the same colour could not appear in more than two consecutive trials. After the appearance of the frame, the subject's task was to drag the cookie to the correct gap as quickly as possible and release it there. If released at any other position, the cookie disappeared and an error message was displayed for 2000 ms. If released above the correct gap, the cookie snapped in place and remained fixed. The colour frame remained visible until the appearance of the visual action effect.

For partner-generated action effects, the partner left his starting position after the subject had dropped the cookie, jumped to a cookie with his index finger and performed a swipe gesture on it to colour it dark brown. Despite the higher similarity between the actions of the two participants compared to Experiment 1, they were still not identical (i.e. dragging and dropping for the subject vs. pointing and swiping for the partner). This choice resulted from the different requirements for these actions: subjects' entire actions needed to be performed on the multi-touch surface to measure their trajectories and thereby enable a characterization of action execution processes. In contrast, CPR were most of all supposed to be fast and emphasize the movement's end point instead of its intermediate phases, to make compatible and incompatible CPR maximally distinguishable.

In compatible blocks, the partner coloured the cookie which the subject had just placed, whereas in incompatible blocks he coloured the one that was located two positions to the left (for target gaps 3 and 4) or right (for target gaps 1 and 2). Thus, again incompatible effects were made completely predictable to avoid any confounding of both factors. In the automatic condition, the cookies were coloured automatically upon the subject dropping them at the target location, while the partner was passively observing the subject's actions with his index finger resting on his starting position. Subjects were instructed to watch the colouring and only then pick the cookie for the next trial, but they were also informed that the visual effects had no relevance for them.

Results

Subjects often initiated a move directly after stimulus onset and only decided which position to go to during the course of their movement. Therefore, the main analysis focused on the total time from stimulus onset until the completion of the move by releasing the cookie. Still, initiation times are reported for completeness. Erroneous responses and trials with initiation times lower below 100 ms or above 2000 ms were excluded from the analyses (3.7 % of the data).

Reaction times

The total duration of a movement was calculated as the difference between cue onset and the release of the cookie on the target location. A repeated measures ANOVA with the factors compatibility (compatible, incompatible) and effect type (partner, automatic) revealed that the main effect of compatibility missed significance, $F(1,23) = 4.090$, $p = 0.055$, $\eta_p^2 = 0.151$. The numerical difference between movements in the compatible and incompatible condition (2046 vs. 2131 ms) was not statistically reliable. Moreover, there was no main effect of effect type and no interaction, both Fs < 1 (see Table 1). Planned comparisons revealed that the numerical compatibility benefit of 78 ms for partner-generated effects was not significant, $p = 0.233$.

To directly test the null hypothesis, namely that the compatibility effects for partner-generated and automatic effects do not differ, the movement time difference between compatible and incompatible blocks was compared between the two effect types. For the resulting t value of 0.086, the JSZ Bayes factor at a sample size of $N = 24$ was $B_{01} = 4.58$, which constitutes positive evidence for the null.

Initiation times were defined as the latency from cue onset until the subject left the starting position with his index finger. The difference between compatible and incompatible reactions (663 vs. 688 ms) failed to reach significance, $F(1,23) = 3.359$, $p = 0.080$, $\eta_p^2 = 0.127$, as did the main effect of effect type and the interaction of both factors, both Fs < 1. The corresponding JSZ Bayes factor for the compatibility effect difference between the partner and automatic condition at $t = 0.194$ was $B_{01} = 4.64$, constituting positive evidence for the null. To test whether this similarity in the compatibility effects can be explained by a transfer from the automatic condition to the partner condition, the analyses of total movement durations and initiation times were repeated with order (partner first vs. automatic first) as an additional between-subjects factor. However, there were no interactions involving order, all Fs < 2 and all ps > 0.3.

Movements of the partner and their relation to subjects' reaction times

One reason for the absence of a compatibility effect for CPR could be that these reactions took a relatively long time to unfold: the partner first needed to process the subject's reaction, then move his hand to the corresponding location and finally perform a gesture on the cookie. Second, it is conceivable that the timing of the partner's reactions differed between compatible and incompatible blocks and thus introduced a confound, whereas this was not the case for automatic effects. To control for such influences, the speed of the partners' reactions and its relation to the compatibility effect in the subjects' movement times were analysed.

A partner's reaction time was defined as the total time between the subject's response and the completion of the partner's gesture on the cookie. A *t* test revealed that these reactions were significantly faster in compatible than incompatible blocks (979 vs. 1065 ms), $t(23) = 4.942$, $p < 0.001$. To determine whether this difference was related to the subjects' compatibility effect, the partner's speed difference between compatible and incompatible blocks was correlated with the subjects' movement time difference. There was no significant correlation, $r = 0.112$, $p = 0.601$ (see Fig. 3b), and neither did the subjects' compatibility effect correlate with the partner's overall mean movement times, $r = 0.166$, $p = 0.439$, or their standard deviations, $r = 0.005$, $p = 0.982$. Thus, the immediacy and variability of the partner-generated effects did not determine the subjects' compatibility effect.

Error rates and movement trajectories

An error was defined as the release of a cookie at any location on the board other than the target gap. Due to the possibility to correct the movement during their course, error rates were very low overall (1.0 %). Furthermore, when an error occurred, this often was due to the system losing track of the subject's finger position. Accordingly, an analysis of the error rates revealed no main effects of compatibility or effect type and no interaction, all Fs < 3 and all ps > 0.1.

Given the low error rates and the lack of a compatibility effect in the errors, it is conceivable that subjects corrected their finger trajectories during the movement in the incompatible condition. If subjects were initially moving towards the wrong location and then only later moving back towards the target, it should be reflected in a deviation from a straight line between the starting position and the target. Therefore, the distances of each sample position from this straight line were added and divided by the number of samples to obtain the mean distance. However, when submitted to a repeated measures ANOVA with the factors compatibility and effect type, both main effects as well as the interaction were far from significance, all Fs < 1. Most importantly, there was no difference between the distances in compatible and incompatible trials (24 vs. 23 pixels, respectively). A separate analysis was performed on the signed deviation values relative to the distractor (i.e. target of the incompatible action effect). That is, samples deviating from a straight line towards the distractor entered the analysis with a positive sign, whereas samples deviating away from the distractor entered with a negative sign. Again, there were no significant main effects or interactions, all Fs < 1.

Discussion

To investigate how goal-directed manual actions are influenced by the compatibility of their resulting CPR, subjects were asked to move virtual cookies to pre-specified locations on a multi-touch table. These actions were followed by a spatially compatible or incompatible colouring of a cookie, which was either produced by a partner's manual reaction or automatically by the computer. Despite a numerical trend for faster reaction times in compatible blocks, the compatibility effect was non-significant, overall, and for CPR, in particular. Moreover, no difference was found in compatibility influences of both effect types.

The absence of a significant overall compatibility effect is at odds with the benefits of compatible action effects that have been reported for different dimensions such as location, intensity and duration (Kiesel & Hoffmann, 2004; Kunde, 2001, 2003; Kunde et al., 2004). Several characteristics of the present paradigm might explain this discrepancy. An obvious difference to other studies is that the arm movements required in Experiment 2 were more complex than the keypress responses that are usually applied, so that compatibility influences might have disappeared in the large variance. Indeed, although they amounted to 85 ms in the present experiment, this constitutes only 4.1 % of the overall movement times (see Table 1). However, as other studies have shown that action effects can influence the planning and control of more complex movements as well (Kunde, Hoffmann, & Zellmann, 2002, Experiment 3), it is unlikely that movement complexity alone can account for the present results.

A similar concern is related to the heterogeneous nature of the movements and target positions. First, due to the relevant positions being located in ten different rows, subjects had to perform movements of very different amplitudes. Second, the target locations were not defined in absolute but in relative terms, so that for example the first gap could be located at any of the first three positions in a row, depending on the location of the pre-positioned cookies. Thus, even when the rule was the same in two trials (e.g. green indicating the second gap), the required movements could still differ in their exact parameters. This variation was necessary, because a constant positioning would have enabled subjects to at least partly infer the response rules beforehand, but it may have contributed to the present findings for a number of reasons.

One factor is that the variable positioning adds considerable variance to the movement times, which should also affect the initiation times, because they typically vary with the duration of an action (Klapp, 1995). However, additional analyses revealed that even when controlling for factors like row or position, the compatibility effect did not become reliable. A second reason concerns the subjects' representations of uniform actions that are necessary for a creation of action–effect linkages. To the degree to which different versions of a reaction (e.g. moving to the third versus fourth absolute position in response to a green frame) were mentally represented as qualitatively different actions, it is possible that no uniform action–effect links have emerged. This weakness of associations may have existed between the effects and either the movements themselves, the target positions, or both (cf. Hoffmann, Lenhard, Sebald, & Pfister, 2009), as neither of them was consistent.

In addition to these problems resulting from the variability within the paradigm, there are two further issues that directly concern the nature of the visual effects in Experiment 2. First, the incompatible positions were not actually associated with a conflicting action, because there always was a cookie located in them. However, this probably cannot explain the results, because previous work suggests that action effect priming more strongly relies on a benefit for compatible rather than a cost for incompatible effects (Hommel, 2004; Kunde et al., 2004). Second, even without any colouring of the cookies, there were several compatible visual effects present for each movement. For instance, subjects necessarily saw their own placing of the cookies and the movement of their hand. Therefore, the colouring itself may not have provided much of an incremental benefit. However, as this is the situation people are faced with in most real-world tasks, it is still considered worthwhile to investigate the role of CPR in this more naturalistic setting.

The present study revealed no compatibility benefit for partner-generated effects specifically, which is remarkable in the light of other investigations where compatibility benefits have been found for social effects in general (Flach et al., 2010; Kunde et al., 2011) and CPR in particular (Experiment 1 of the present study; Pfister et al., 2013). One possible reason for the absence of CPR compatibility effects is that CPR were more temporally removed from the subject's response. Their temporal delay did not correlate with the compatibility effect, suggesting that the delay's magnitude was not a critical factor. However, this does not exclude the possibility that the mere presence of a delay attenuated compatibility influences. Second, as CPR contained the entire movement from a neutral position to the target location, their appearance was highly similar between compatible and incompatible effects for the main part of the movement. This might have further decreased the influence of CPR compatibility.

Finally, automatic effects might have been easier to integrate with the actions, because they did not make it likely for subjects to shift their attention away from the target location. This is different for CPR, because the partner's movement began at his starting position. If that movement as a sudden visual onset captured subjects' attention (cf. Theeuwes, Kramer, Hahn, & Irwin, 1998), this would imply that they had to disengage their attention from the effect location only to bring it back later. Such an interruption might have flattened the relevance of this location and therefore the impact of anything that was happening there. In principle, the same explanation should hold for Experiment 1, but it is possible that the biological, whole-arm movements used in Experiment 2 captured attention more strongly than the small, abstract mouse cursor.

Despite these concerns about the characteristics of the CPR, it should be noted that the CPR compatibility effect did not statistically differ from that of automatic effects. Also, the time difference between movements followed by compatible versus incompatible CPR was subject to a high amount of variance (with compatibility effects ranging from −523 to 866 ms, see Fig. 3b). With all this variability in the present paradigm, the absence of compatibility effects should not be over-interpreted.

Experiment 3

The results of Experiment 2 suggest that it is not easy to transfer some of the findings from simplistic laboratory settings to more naturalistic joint tasks. However, it is not clear whether the absence of CPR compatibility effects was really caused by the more naturalistic character of the task itself, or by the methodological difficulties discussed before. On the one hand, it could be a genuine feature of naturalistic joint action settings. For instance, the goal-directed action might shift people's attention to the outcome and away from the specific actions per se.

On the other hand, if the absence of compatibility effects was caused by methodological factors, an extension of ideomotor theory and response–effect compatibility phenomena to joint tasks would still be possible. Therefore, a third experiment was conducted that used a similarly naturalistic and complex paradigm, but eliminated some of the methodological shortcomings of Experiment 2. For that purpose, the temporal compatibility of hand gestures was varied. In a multi-touch setup, subjects changed the colour of virtual objects by performing either fast or slow swipe gestures on them. After gesture completion, a partner performed a swipe gesture on his own object, and its speed either consistently resembled that of the subject's gesture (compatible), was opposite to it (incompatible), or was chosen randomly (unpredictable).

In studies of automatic imitation, duration and speed have rarely been used as the action feature of interest (for an exception see Watanabe, 2008). However, the use of temporal CPR compatibility as an experimental manipulation has several benefits. First, actions can be spatially confined and thus are highly uniform across trials. Second, the feature constituting the compatibility is inherent in the action itself and not only in its target, so that the CPR's compatibility is visible throughout the entire performance of a gesture. Moreover, as the movement itself constitutes the attended feature, this is likely to increase the involvement of the action simulation processes. Third, temporal compatibility manipulations make it possible to use the same type of gesture for both participants, thereby increasing the degree of dimensional overlap between actions and their effects. Together, these features should provide optimal conditions for CPR influences to be observable. Therefore, it is hypothesized that subjects will be faster to initiate their actions in compatible blocks, when knowing that the partner will respond with an action of similar speed.

Besides action initiation, processes of action execution might also be affected by temporally compatible or incompatible swipe gestures. Such influences could be expected in the movement durations as well as in the gestures' velocity profiles. In terms of movement durations, there are two possible outcomes. First, if not only observing but also anticipating another person's actions leads to an activation of the corresponding feature codes and this activation transfers to action performance, actions should become similar to the anticipated CPR. For instance, expecting a slow CPR might slow down the subject's own movement as well. However, previous studies investigating execution parameters in the context of response–effect compatibility paradigms (Kunde, 2003; Kunde et al., 2004) have reported contrast effects instead. That is, subjects' actions became more different from their anticipated effects. For instance, when subjects expected a long tone to follow their button presses, the duration of these button presses was reduced (Kunde, 2003). Therefore, if the impact of CPR indeed resembles that of automatic effects (as suggested by Experiment 1 and Pfister et al., 2013), Experiment 3 should reveal contrast effects as well. Observing such effects would be especially interesting, because the long onset latencies of CPR would make a previously suggested explanation of these effects rather unlikely, namely that they result from the formation of compound effect representations. This issue will be followed up in the discussion.

Besides a general modulation of movement durations, the gestures' velocity profiles might depend on compatibility. The experimental setup allows subjects to initiate an action rather spontaneously and then correct it online. If this is what subjects do, an anticipation of incompatible CPR might make them start at the wrong speed and then either slow down or speed up to match the currently required speed. This could affect the velocity profiles in two ways. First, the speed change from the start to the end of a gesture should be higher for incompatible than compatible blocks. Second, the area under the curve (AUC), or deviation of the velocity curve from a straight line, should reflect the discontinuity of subjects' gesture speed. This discontinuity is assumed to be higher in the incompatible condition if subjects start at a particular speed and then suddenly brake or speed up when noticing that their chosen speed was wrong.[2]

A final goal of Experiment 3 was to distinguish the impact of compatibility from that of predictability. After all, it could be argued that an influence of CPR compatibility is hard to find because subjects can simply recode their mental representation of the partner's reactions (cf. Hommel, 1993). Indeed, when the context requires complementary actions by two people, an observation of other people's actions that are dissimilar to one's own can result in even stronger motor simulation processes than similar actions (Newman-Norlund, van Schie, van Zuijlen, & Bekkering, 2007; Sartori, Bucchioni, & Castiello, 2012). One previous study has directly contrasted the impact of the compatibility versus predictability of another person's reactions to subjects' actions (Catmur & Heyes, 2013), showing that the prosocial effects of being imitated depend on predictability more strongly than compatibility. However, no studies so far have examined the relative influences of CPR compatibility and predictability on action control processes. Therefore, in Experiment 3 a third block was added in which the partner responded to subjects' movements by randomly choosing a gesture speed. If not only the mismatch of CPR but also their lack of predictability decreases performance, planned comparisons should reveal differences between the compatible and unpredictable, but not between the incompatible and unpredictable block.

Some previous work has suggested that the influence of action effects might be particularly strong for intentionally chosen as opposed to stimulus-driven actions (Herwig, Prinz, & Waszak, 2007). To test whether this difference between action modes affected the impact of CPR on action

[2] Note that in the present multi-touch setup, the virtual objects lacked any haptic boundaries and thus did not pose clear restrictions on subjects' movement amplitudes. In consequence, subjects did not slow down when approaching the end of the object, but extended their swipe gesture way beyond its boundary. Therefore, any speed changes within the measured area were fairly monotonic.

planning, Experiment 3 also included trials in which subjects were free to choose their movement speed. Moreover, as Experiments 1 and 2 had not revealed any indications for a modulation of compatibility influences by effect type (partner vs. automatic), this factor was dropped in Experiment 3.

Methods

Subjects

Twenty-four students of the Technische Universität Dresden (18 female) in the age range of 20–35 years ($M = 25.8$, $SD = 4.1$) participated in the study in exchange for course credit or a payment of 5€ per hour. The experimenter acted as the partner for all subjects.

Apparatus and stimuli

The experiment was performed on a M2467PW multitouch monitor (3M) with a display size of 24″ and a spatial resolution of 1920 × 1080 pixels, which was rotated horizontally. The participants were seated opposite to each other at the two long sides of the table. On the left side of the table from the subject's perspective, each participant had a pile of fifteen oval virtual objects per miniblock, with a size of 350 × 100 pixels each. The subject's objects were green and the partner's were red. A grey board in the centre of the table served as the joint workspace for performing the swipe gestures of interest. The frame of this workspace was dark grey in the beginning of each trial and later changed its colour as a cue to indicate the required speed (orange—fast, blue—slow, purple—free choice). During the relevant object colouring phase of each trial, objects were fixed at a pre-specified position on the workspace. Eight pixels in front of that position there was a circular starting position of 62 pixels diameter, on which participants had to place their right index finger before performing their swipe gesture. Upon placing the finger, the starting position turned red to indicate that the touch had been detected. Objects turned white after a swipe gesture as soon as the finger crossed their far border, exiting the object. On the right side from the subject's perspective there was a grey board on which the objects had to be put after both partners had finished their actions. An overview of the experimental setup is provided in Fig. 1c.

Procedure

The experiment consisted of three parts that varied the relation between the subject's actions and the partner's reactions (compatible, incompatible, unpredictable). Block order was counterbalanced across subjects. Each block consisted of a practice miniblock and five experimental miniblocks, with each miniblock corresponding to a pile of 15 objects, one of which had to be coloured in each trial. Accordingly, the experiment as a whole consisted of 225 experimental trials and 45 practice trials.

In each trial there were three phases, a pre-phase, a main phase and a post-phase. The pre- and post-phases were included to increase the experiment's appearance as a naturalistic joint action task. During the pre-phase, both participants dragged one object from their pile to the workspace, and upon releasing it anywhere above the workspace it snapped to its fixed position. The main phase started as soon as both participants had placed their right index finger on their respective starting positions. With a delay of 500 ms, the cue (coloured frame around the workspace) appeared and indicated the speed for the subject's gesture. In fast trials, the object had to be coloured with a swipe gesture that took no longer than 400 ms from entering the object at its near end until leaving it at its far end. Slow trials required movements with a duration of more than 400 ms, and in arbitrary trials subjects were free to move either fast or slow. However, they were instructed to clearly decide for one speed in each trial, to decide randomly and to perform both speeds about equally often. Each colour cue appeared five times per miniblock and the cue order was randomized. In case of an invalid action (i.e. performing the movement at the wrong speed, lifting the finger during the movement, or crossing the object's border before having covered a distance of at least 75 % of its length), an error message appeared as a pop-up, remained on the screen for 2000 ms and the trial was aborted. After the subject had completed his movement, the partner reacted by also performing a swipe gesture on his own object. Only when he was finished, both participants could drag their objects to the final board and release it there, which made them get stacked automatically. The following trial started whenever participants were ready and took the next objects from their piles.

Results

All invalid trials according to the criteria listed above as well as trials with initiation times longer than 2000 ms were excluded from the analyses (2.5 % of the data). The remaining data were submitted to repeated measures ANOVAs with the factors choice (instructed, free), speed (fast, slow) and relation (compatible, incompatible, unpredictable).

Initiation times

The initiation time of a movement was computed as the latency between the onset of the colour cue and the subject leaving the starting position. There were significant main effects of choice, $F(1,23) = 103.676$, $p < 0.001$, $\eta_p^2 = 0.818$, speed,

$F(1,23) = 196.504$, $p < 0.001$, $\eta_p^2 = 0.895$, and relation, $F(2,46) = 4.749$, $p = 0.013$, $\eta_p^2 = 0.171$, as well as an interaction of choice and speed, $F(1,23) = 14.465$, $p < 0.001$, $\eta_p^2 = 0.386$. No other interactions were significant, all Fs < 3 and all ps > 0.08. Freely chosen movements were initiated slower than instructed movements (1056 vs. 896 ms), fast movements were initiated faster than slow movements (821 vs. 1131 ms), and this difference between slow and fast trials was most pronounced for instructed movements. Initiation times preceding compatible CPR (950 ms) were faster than those preceding incompatible CPR (1008 ms), $p = 0.027$, but did not significantly differ from initiation times in the unpredictable condition (970 ms), $p > 0.8$ (see Fig. 4a).[3]

Movement durations

Movement duration was calculated as the time from the subject's finger entering the object until leaving it again. There were significant main effects of speed, $F(1,23) = 154.981$, $p < 0.001$, $\eta_p^2 = 0.871$, and relation, $F(2,46) = 5.994$, $p = 0.005$, $\eta_p^2 = 0.205$, as well as an interaction of speed and relation, $F(2,46) = 6.897$, $p = 0.002$, $\eta_p^2 = 0.231$. No other main effects or interactions were significant, all Fs < 3 and all ps > 0.1. Not surprisingly, fast movements took less time than slow movements (152 vs. 1167 ms). Movement durations were shorter in compatible than incompatible and unpredictable blocks, both ps < 0.03, whereas these two latter conditions did not differ from each other, $p > 0.9$. However, the interaction of relation and speed revealed that this time reduction in compatible relative to incompatible and unpredictable blocks was due to slow movements only (1035 vs. 1237 and 1230 ms), both ps < 0.03, whereas for fast movements there were no significant differences (158, 148 and 150 ms), all ps > 0.1. Thus, when subjects performed slow movements, they performed them about 200 ms (16 %) faster when expecting the partner to react with a slow movement as well than when expecting him to move fast or having no expectation (see Fig. 4b).[4]

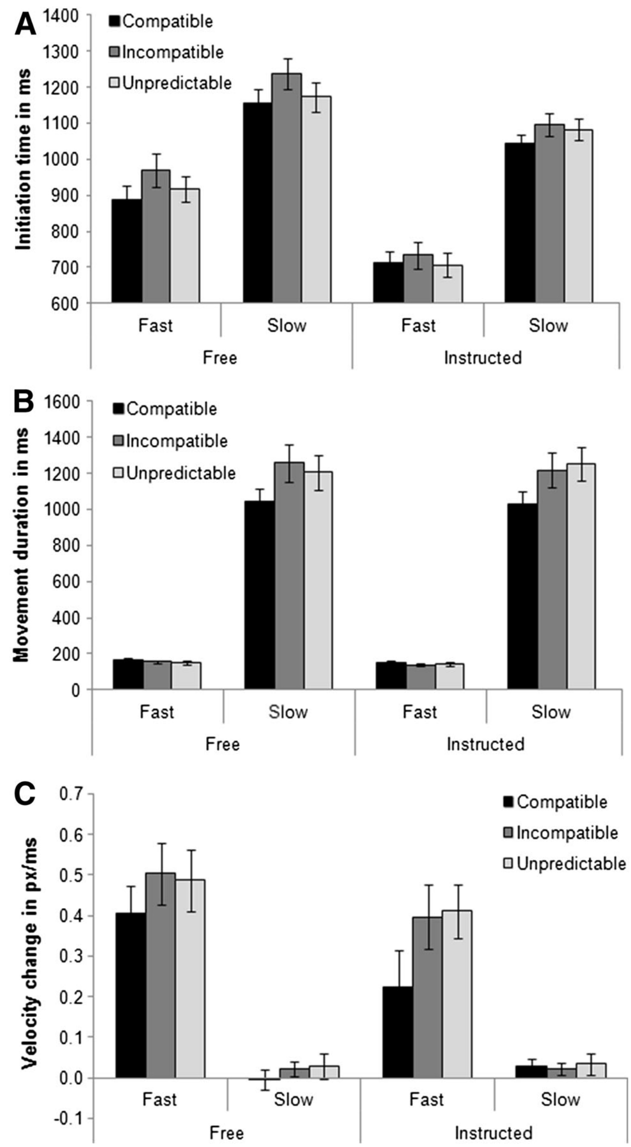

Fig. 4 Initiation times (**a**), movement durations (**b**) and velocity changes from the start to the end of a swipe gesture (**c**) in Experiment 3 for compatible, incompatible and unpredictable partner reactions, depending on speed and choice. *Error bars* represent standard errors of the mean

[3] A previous study examining the temporal compatibility of action effects (Kunde, 2003) analysed the data in a different way, by computing the interaction of action duration and effect duration. This procedure was not adopted in Experiment 3 to make the analysis procedure consistent with that used in Experiments 1 and 2. However, to facilitate the comparison with Kunde's study, the data were reanalysed accordingly: initiation times from compatible and incompatible blocks were collapsed across the two choice conditions and a repeated measures ANOVA entered with the factors action duration and CPR duration. There was a main effect of action duration, $F(1,23) = 163.576$, $p < 0.001$, $\eta_p^2 = 0.877$, and an interaction with CPR duration, $F(1,23) = 6.753$, $p = 0.016$, $\eta_p^2 = 0.227$. Fast actions were initiated more quickly than slow actions, and compatible mappings (i.e. fast actions being followed by fast CPR and slow movements by slow CPR) led to shorter initiation times than incompatible mappings. However, the main effect of CPR duration was absent, $F < 1$, indicating that initiation times for actions that triggered fast effects were not generally shorter than those triggering slow effects. The latter result diverges from previous findings (Kunde, 2003).

[4] Analogous to the initiation times, movement durations were reanalysed with the factors action duration and CPR duration. There were main effects of action duration, $F(1,23) = 149.705$, $p < 0.001$, $\eta_p^2 = 0.867$, CPR duration, $F(1,23) = 7.520$, $p = 0.012$, $\eta_p^2 = 0.246$, and an interaction, $F(1,23) = 6.062$, $p = 0.022$, $\eta_p^2 = 0.209$. Fast movements were performed faster than slow movements, and movements with slow CPR were performed faster than movements with fast CPR. Moreover, with a compatible mapping movements were performed faster than with an incompatible mapping. The presence of an interaction for the movement durations is in contrast with the findings of Kunde (2003).

Movements of the partner and their relation to subjects' initiation times

A partner's movement duration was defined as the time between entering and exiting his object. To test whether this duration differed between the experimental conditions, a repeated measures ANOVA with the factors partner speed and relation was computed. There were significant main effects of partner speed, $F(1,23) = 453.063$, $p < 0.001$, $\eta_p^2 = 0.952$, and relation, $F(2,46) = 10.549$, $p < 0.001$, $\eta_p^2 = 0.314$, as well as an interaction, $F(2,46) = 12.107$, $p < 0.001$, $\eta_p^2 = 0.345$. Fast partner movements had shorter durations than slow movements (134 vs. 962 ms), and overall the partner's movements were faster in the compatible condition than the incompatible and unpredictable conditions (507 vs. 574 and 564 ms), both $ps < 0.005$. Moreover, this difference between the relation conditions was selectively due to slow movements, whereas for fast movements none of the relation conditions differed from the others, all $ps > 0.1$. Thus, the partner's movement duration results mirrored those of the subjects.

To test whether these differences in the partner's movement speed might account for the compatibility effect in subjects' initiation times, the initiation time difference between compatible and incompatible blocks was correlated with the corresponding difference in the partner's movements. As in previous experiments, there was no significant correlation, neither for the overall compatibility effect across movement speeds, $r = 0.043$, $p = 0.844$ (see Fig. 3c), nor for slow movements alone, $r = 0.171$, $p = 0.424$. Thus, the difference between the partner's movements in compatible versus incompatible blocks most likely did not determine subjects' compatibility effect.

Error rates and velocity profiles

An error was defined as a movement performed by the subject that did not conform to the currently instructed speed and thus errors were only possible in the instructed condition. Overall, error rates were low (1.8 %). A repeated measures ANOVA including the factors speed and relation revealed a main effect of speed, $F(1,23) = 9.510$, $p = 0.005$, $\eta_p^2 = 0.293$, but no effect of relation, $F(1,23) = 2.467$, $p = 0.096$, $\eta_p^2 = 0.097$, and no interaction, $F < 1$. Fewer errors were committed for fast movements than slow movements (0.7 vs. 2.8 %) and, while errors were numerically more frequent in compatible blocks than incompatible and unpredictable blocks (2.8 vs. 1.5 vs. 1.0 %), there were no significant differences between the three conditions, all $ps > 0.1$.

As responding was not ballistic, but a temporally extended action that could be changed during the process, it is possible that in some trials subjects started with the wrong speed and then corrected their movement online. To test whether the relation between actions and CPR modulated subjects' velocity profiles, for each multi-touch sample the velocity was calculated and a moving average over three samples was computed. From these values, the overall velocity change within a movement from its start to its end and the deviation of the velocity curve from a straight line (area under curve, AUC) were derived. Both measures were computed separately for the absolute and the signed values.

In the signed velocity changes from the start to the end of a movement, there were main effects of choice, $F(1,23) = 9.593$, $p = 0.005$, $\eta_p^2 = 0.294$, speed, $F(1,23) = 38.432$, $p < 0.001$, $\eta_p^2 = 0.626$, and relation, $F(2,46) = 3.546$, $p = 0.037$, $\eta_p^2 = 0.134$, as well as an interaction of choice and speed, $F(1,23) = 9.200$, $p = 0.006$, $\eta_p^2 = 0.286$. The interaction of speed and relation missed significance, $F(2,46) = 2.941$, $p = 0.063$, $\eta_p^2 = 0.113$ (see Fig. 4c). No other interactions were significant, all $Fs < 2$, all $ps > 0.2$. The velocity change was higher for freely chosen than instructed movements (0.241 vs. 0.186 px/ms) and much higher for fast than slow movements (0.405 vs. 0.022 pixels/ms), while the latter difference was more pronounced in free choice trials. More importantly, the descriptively lower speed change in compatible than incompatible and unpredictable blocks (0.164 vs. 0.236 and 0.240) was not significant, both $ps > 0.07$.

The absolute velocity changes as well as the signed and absolute deviations from a straight line did not reveal any main effects or interactions involving relation, all $Fs < 3$ and all $ps > 0.07$.

Discussion

Whereas the simplistic Experiment 1 had found compatibility effects for CPR, the more naturalistic Experiment 2 had not. Therefore, the goal of Experiment 3 was to test whether CPR compatibility effects can be observed in a naturalistic setting that eliminates some of the methodological shortcomings of Experiment 2. In a joint multi-touch experiment, participants manipulated objects with swipe gestures of varying speeds that triggered temporally compatible, incompatible or unpredictable partner reactions. Initiation times were shorter with compatible than incompatible CPR, indicating that the anticipated reactions of a partner can influence action planning even in more naturalistic joint tasks. This suggests that the absence of CPR compatibility effects in Experiment 2 can probably be attributed to the particular features of the experimental setup.

Experiment 3 extends previous knowledge in two ways. First, it examines the impact of action effects that are not absolute, but vary within a certain range. As a human partner can neither perform movements of exactly the same speed across trials nor perfectly adjust his speed to that of the subject, the partner-generated action effects varied both in their uniformity and their degree of being compatible or incompatible. While for fast partner reactions ($M = 134$, SD = 61, 37–392 ms) this variability was rather limited and 60 % of the data were in the range of 70–130 ms, slow partner reactions varied considerably ($M = 962$, SD = 240, 409–2203 ms), with 60 % of the data being evenly distributed over a range of 800–1200 ms. The presence of a significant compatibility effect in the initiation times suggests that this variation does not keep subjects from recruiting mental representations of the partner's reactions for action planning. This makes sense from the perspective of acting in the real world, where action effects are often neither uniform nor perfectly matched with the person's own actions (e.g. when a ball is thrown and perturbed by the wind). A large body of research has investigated the mechanisms by which humans learn to distinguish such external perturbations of perceivable action effects from their own influence (Blakemore, Goodbody, & Wolpert, 1998; Wolpert, Diedrichsen, & Flanagan, 2011). An interesting challenge for future research will be to specify how it depends on the CPR's variability whether people mentally represent CPR as a consequence of their own actions versus an externally caused event (Pfister, Obhi et al., 2014) and how this determines whether CPR are recruited for action planning.

Second, the present experiment enables a differentiation between the influences of CPR compatibility versus predictability. Relative to compatible blocks, initiation times were only slowed down in incompatible, but not in unpredictable blocks. This result contrasted with a recent study investigating the impact of compatibility versus predictability on more subjective consequences of being imitated and found that predictability was more important (Catmur & Heyes, 2013). Indeed, even in the present study the informal reports of some subjects revealed that they preferred incompatible CPR to unpredictable reactions. However, this subjective evaluation does not seem to extend to the ease of action control. This result can be explained from a common coding perspective (Hommel et al., 2001; Prinz, 1997) in which the same cognitive codes are used for mentally representing action effects and performing actions. Thus, the anticipation of an incompatible CPR should activate the corresponding movement features and thereby impair the performance of the currently required movement. Instead, if no anticipations can be formed in the unpredictable condition and therefore no competing codes are activated, no impairment should occur.

Still, these results are not trivial, because previous research suggests that action effect influences mainly stem from a facilitation by compatible instead of an impairment by incompatible effects, and thus the use of action effects is at least partly strategic (Hommel, 2004). In contrast, the present results are more in line with an incompatibility cost. It is unlikely that this results from a higher similarity of unpredictable blocks to compatible than incompatible blocks, because in unpredictable blocks non-matching trials (54.3 %) are even more frequent than matching trials. On the other hand, these divergent findings might reflect a genuine difference between social and non-social action effects, which would fit with the notion that influences of social stimuli on perception and action are less susceptible to strategic processes (Frischen, Bayliss, & Tipper, 2007; Gowen & Poliakoff, 2012).

The partners' reactions also affected parameters of movement execution. The modulation of the gestures' velocity profiles by the relation between action and partner reactions was rather weak. As expected, for the signed velocity changes over the course of a gesture there was an overall influence of relation, with the numerically smallest speed changes for compatible blocks. However, in the planned comparisons no significant differences were found. Similarly, there were no influences of relation on the deviations of the velocity curves from a straight line. Thus, the present experiment does not provide strong evidence that subjects corrected their movement speed on the fly when anticipating incompatible CPR.

A more obvious modulation was found in the movement durations. While fast movements were not modulated by the CPR relation (perhaps, because their short durations of less than 200 ms did not leave much room for adaptation), slow movements were strongly affected: they were performed faster when being followed by compatible (i.e. also slow) CPR than by incompatible (i.e. fast) or unpredictable reactions. It is possible that the mechanisms underlying these contrast effects differ from those suggested by Kunde (2003), namely an averaging of effect representations from different modalities (i.e. kinesthetic and auditory). Such an account would be highly unlikely in the present experiment, because effect averaging typically requires very short time windows of around 70 ms between the action and its effect (Aschersleben & Prinz, 1997). The partner's mean initiation time of 542 ms clearly exceeds this latency. An alternative possibility is that the contrast effects were caused by strategic processes. For instance, subjects might have increased their effort of adhering to their plan of performing a slow movement when being confronted with distraction from the partner's non-matching reaction.

However, a confound in the present paradigm would make it premature to settle on any explanation. As the title of Pfister et al.'s (2013) study emphasizes, "it takes two to imitate", which implies that both participants are susceptible to compatibility influences in joint response–effect compatibility paradigms. In Experiment 3, this is reflected in the finding that not only subjects, but also the partner moved most quickly in compatible blocks. This difference in CPR duration cannot directly affect the durations of subjects' slow movements by way of effect anticipation. The reason is that in incompatible blocks, a slow subject movement was never followed by a slow CPR and thus cannot have been affected by the CPR's slowness. However, the partner's higher movement speed in compatible blocks may have resulted in a general priming of fastness, or even have set an implicit norm for the speed at which a slow movement is to be performed. If this was the case, non-ideomotor accounts might explain the movement duration results. Future studies will have to test both accounts against each other, for example by using ostensive partners who can perform identical reactions in compatible and incompatible conditions.

General discussion

The present study investigated whether it is easier to perform an action when anticipating a partner to respond in a compatible manner. Two experiments manipulated the spatial overlap of contingent partner reactions (CPR) and automatic effects with the subject's manual actions, while a third experiment manipulated their temporal compatibility and predictability.

In Experiment 1, a close replication of the spatial response–effect paradigm (Kunde, 2001) was conducted, and automatic action effects were compared with a joint condition in which the same effects were produced by another person's mouse actions. The basic phenomena could be replicated in the joint version: spatial keypress reactions were initiated faster when they were responded to by the partner moving his mouse to a corresponding location to produce a visual effect. This influence of CPR was particularly pronounced for relatively slow reactions and did not differ from that of automatic effects. Moreover, it did not decrease when the partner's mouse movements were slower or more variable. The latter finding suggests that the inevitable latency and non-uniformity of a human's reactions does not necessarily keep them from exerting the same influence as automatic action effects.

Experiment 2 was set up to test the impact of CPR compatibility in a more complex joint object manipulation task, in which subjects had to manually relocate and manipulate virtual cookies on a multi-touch display. No significant compatibility effects were found. Again, the data revealed no differences between the influence of compatibility in partner-generated and automatic action effects, and no modulation by the latency or variability of the partner's hand movements.

Finally, Experiment 3 was conducted to rule out a possible explanation for the lack of CPR compatibility effects in Experiment 2, namely that a partner's reactions simply were non-influential in more naturalistic joint action tasks. Therefore, a similarly complex task was used in which virtual objects were coloured with swipe gestures, and temporal compatibility was varied to eliminate some of the methodological difficulties of Experiment 2. This time, the initiation times revealed a significant difference between compatible and incompatible CPR and a contrast effect in the movement durations: when followed by compatible CPR, slow movements were performed faster than when followed by incompatible or unpredictable CPR. These results indicate that the fit between a person's actions and the partner's subsequent reactions can play a role for action control even in joint action settings.

The compatibility of anticipated partner reactions can affect action planning

The present results show that in principle, it is possible for a representation of another person's reaction to facilitate the actions that bring this reaction about. Accordingly, priming by another person's actions is not restricted to situations in which they precede the subject's actions or occur in parallel (as in studies of visuomotor priming and interference, e.g. Brass et al., 2001; Stanley et al., 2007; Stürmer et al., 2000). Instead, the mere anticipation of a partner's reactions to one's own actions can result in similar facilitation effects.

Furthermore, the present results suggest that an influence of anticipated CPR can occur when these reactions are depicted with low visual salience and in an indirect manner, for instance via a spatial indicator such as a mouse cursor (cf. Stanley et al., 2007). Also, such priming is even possible when the two actions are quite different in their movement specifics and visual features, as in the case of keypresses and mouse movements (Experiment 1). In that sense, CPR compatibility effects are not restricted to situations in which the subject's actions are literally imitated (Pfister et al., 2013). What seems to be more relevant than similarity is the overlap of both actions' outcomes or end states (e.g. acting on a particular location or object). Similar conclusions have been drawn from studies of imitation, where the influence of a model's actions on a subject's subsequent actions also depends on their end state more than on intermediate states or specific movement parameters (Csibra, 2007; Stürmer et al., 2000).

Taken together, the influence of another person's reactions seems to be very similar to that of automatically generated sensory action effects (Kunde, 2001, 2003; Kunde et al., 2004), despite their lower uniformity and predictability, and despite the fact that they are not directly caused by the actions preceding them. However, the present results also show that whereas visuomotor priming by CPR is possible in principle, it is not something that occurs under all conditions. Despite its spatial overlap with the subject's actions, in Experiment 2 a compatible colouring of objects did not cause significant facilitation. As discussed before, several factors may have prevented compatibility effects from becoming strong enough in this experiment. On the other hand, if the phenomenon was highly robust, it would probably have survived these influences.

One potentially important factor for the priming of actions by anticipated partner reactions is the relevance of the partner's reactions for the subject. Generally, task-irrelevant action effects sometimes are inconsequential (Ansorge, 2002), and this might be even more important in social settings. Natural joint tasks usually rest on mutual dependencies between the co-actors, so that a partner's reactions will guide a person's subsequent actions. Such forward influences were completely neglected in the present study: at the time of the CPR, the subject had already finished his part of the task and could basically ignore what the partner was doing. Due to this rather artificial reduction of the CPR's relevance, a generalization from the present results to natural joint action settings is not without problems. Therefore, future studies should examine the role of mutual dependencies in determining how a partner's anticipated reactions affect action planning.

No differences between human and machine

None of the experiments revealed any reliable differences in the influence of partner-generated versus computer-generated effect compatibility, and the Bayes factor analyses provided positive evidence for the null hypotheses. Thus, CPR seem to exert the same influence on behaviour as automatic action effects. This result is somewhat surprising, given that in many social paradigms, a higher impact of human actions than machine actions has been reported (Gowen & Poliakoff, 2012; Liepelt & Brass, 2010; Stanley et al., 2007; Tsai, Kuo, Hung, & Tzeng, 2008; Wiese, Wykowska, Zwickel, & Müller, 2012). A possible explanation for this discrepancy might be based on the different functions and task-relevance of the stimuli used in these paradigms versus those of action effects. For instance, studies of automatic imitation typically use task-irrelevant imitation stimuli which distract subjects from their actual task and randomly prime the wrong action in half of the trials. Therefore, the best strategy is to ignore them, which seems to be harder for human than non-human stimuli.

In contrast, phenomena of effect compatibility might not be a matter of "involuntary capture", but the attention to effects might even be somewhat strategic (Hommel, 1993, 2004). In the present study, the effects were potentially helpful by predictably and validly priming the correct response during one entire half of the experiment, regardless of who was producing these effects (human or machine). Therefore, attending to both types of compatible effects might have been voluntary and beneficial. In accordance with that, the influence of visual effects is stronger when these effects are attended (Janczyk, Pfister, Crognale, & Kunde, 2012). Furthermore, it is possible that the balance between strategic versus involuntary attending is modulated by the visual appearance or social relevance of CPR.

However, there are also studies showing that the influence of human actions is not always as social as one might assume. For instance, the joint Simon effect which has been taken as a key indicator of task co-representation (Sebanz, Knoblich, & Prinz, 2003) can be reproduced in the presence of inanimate, but salient entities such as a Japanese waving cat or metronome (Dolk, Hommel, Prinz, & Liepelt, 2013). Together with these findings, the lack of a difference between human and computer-generated effects in the present study is compatible with the notion that other humans and their actions are at least sometimes represented just like any other event (Dolk et al., 2014; Hommel, 2013).

Partners are also not immune to compatibility influences

In all of the experiments reported here, the partner's reactions were faster in the compatible than the incompatible condition. This corresponds with the results of numerous studies on automatic imitation, showing that it is easier to perform actions that match the observed actions of others (Heyes, 2013). However, this might constitute a confounding factor to the interpretation of the subjects' compatibility effects. Specifically, it has been shown that a longer duration of action effects also increases initiation times (Kunde, 2003). Therefore, the compatibility benefits reported in the present study might merely be a consequence of the anticipated CPR being shorter.

Two aspects of the present data do not support this assumption. First, in none of the experiments the subjects' compatibility effects were correlated with those of the partner. Second, in Experiment 3 the initiation time compatibility effects did not vary as a function of the required speed. This means that even when subjects performed a slow movement and expected the partner to react with a slow movement, they were faster than when they expected a fast movement. If effect duration had been a major factor in determining the results, the compatibility benefit should either have been absent for slow movements or at least have been larger for fast movements. However, although the duration of *anticipated* effects cannot fully account for the present results, it is still possible that the overall faster actions of the partner in compatible blocks might have resulted in a (non-anticipatory) priming of higher response speed.

These considerations highlight a serious problem of using real human partners in the study of ideomotor influences on joint action. Therefore, a possible conclusion would be to restrict investigations to more closely controlled paradigms that use simulated partner reactions such as pictures, videos or virtual agents (e.g. Kunde et al., 2011; Pfeiffer, Timmermans, Bente, Vogeley, & Schilbach, 2012). However, although this approach certainly has its own merits, it should not replace real joint action tasks, because the latter can extend our knowledge about effect anticipations in unique ways.

This is due to a number of differences between CPR and automatic action effects. First, CPR are not directly caused by the subject, but by an intentional agent that is separate from the self and thus can inform us about the impact of stimuli that contingently follow our actions in the clear absence of direct causal links. Along these lines, the study of CPR compatibility can even be extended to situations in which there is not even an indirect causal relationship between the actions of both participants. This might occur for instance when a common environmental factor brings about the perfect correlation between these actions. Second, the higher variability of CPR in terms of their latency and execution distinguishes them from automatic effects. Strictly speaking, it is not possible to perform two hand gestures that are exactly identical. Therefore, CPR are a promising way to examine the degree to which action effect bindings can generalize to non-identical stimuli. By manipulating the variability and uniqueness of the partner's reactions, the conditions and limits of this generalization can be examined. Third, in the joint action literature, it has been shown that the amount of representing another person's task and simulating his actions is a function of being directly engaged in an interactive task with that person (Kourtis, Sebanz, & Knoblich, 2010). Therefore, real partners should not be eliminated from our paradigms for the sake of experimental control when studying joint action.

Conclusions and future directions

The present study shows that spatially compatible reactions by a partner can facilitate the planning of actions, similar to automatic action effects. This is possible even in more naturalistic joint action tasks in which two participants perform goal-directed movements to manipulate objects. However, this transfer of basic findings to applied settings still seems to require a relatively close control of the involved action and reaction parameters. Future studies will test the conditions under which an influence of partner reactions can be observed. They will vary the level of interdependence between two participants as well as the attentional demands of the task and investigate the impact of partner reactions that share features with subjects' actions on other dimensions such as gesture type or language.

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