Temporally compatible partner reactions facilitate action initiation and produce contrast effects on movement duration

Romy Müller (romy.mueller@tu-dresden.de)
Applied Cognitive Research Unit, Technische Universität Dresden, Zellescher Weg 17,
01069 Dresden, Germany

Abstract

When we are able to anticipate other people's reactions to our own actions, these anticipations can modulate action selection processes. However, it is unclear whether such influences can also emerge in more naturalistic joint action scenarios. Therefore, the present study used a joint temporal response-effect compatibility paradigm in which two people manipulated virtual objects on a multi-touch table. Subjects performed slow or fast swipe gestures and after each gesture a partner responded with either a slow or fast gesture. Three experimental blocks varied whether the subject's gesture triggered a partner gesture that was compatible, incompatible, or unpredictable in terms of its speed. Initiation times were higher for incompatible than compatible blocks, whereas unpredictable partner reactions did not result in a slowdown. Movement durations revealed a contrast effect: When a slow movement was required and subjects expected the partner to move slowly as well, their gestures were faster than when they expected the partner to move fast or had no expectation. The results show that core findings from the response-effect compatibility paradigm can be reproduced in a joint task, thereby highlighting ideomotor theory as a promising framework for studying joint action.

Keywords: joint action; ideomotor theory; action effects; temporal compatibility

Introduction

Our actions are affected by the actions of other people. This has thoroughly been investigated in the context of automatic imitation (for an overview see Heyes, 2011), with numerous studies showing that it is easier to perform an action when concurrently observing another person perform a similar action. However, recent studies suggest that the influence of another person's actions on our own behavior is not restricted to settings in which that action plays the role of a stimulus. Instead, such influences can also be demonstrated in the reverse direction, namely when a subject's action triggers either compatible or incompatible reactions by a partner. In these settings, a mere anticipation of compatible partner reactions can facilitate action planning (Müller, 2013b; Pfister, Dignath, Hommel, & Kunde, 2013). For example, subjects were able to initiate button presses of particular durations faster when they knew that after their button press another person would press a button with the same duration (Pfister, et al., 2013). Thus, other people's actions can influence us even before they have actually happened but we are merely expecting them.

Such findings have been interpreted in the framework of ideomotor theory (Hommel, Müsseler, Aschersleben, & Prinz, 2001). This theory postulates that when actions are contingently followed by perceivable changes in the environment – so-called action effects – this leads to a formation of bi-directional links between the action and the effect. As a consequence, a mere anticipation of the effect gains the power to trigger its corresponding action. Evidence for this action-inducing ability of effect anticipations stems from the response-effect compatibility paradigm (Kunde, 2001). In this paradigm, actions are contingently followed by effects that are either compatible or incompatible with the action in terms of their spatial parameters, duration, intensity, or other dimensions (e.g. Janczyk, Pfister, Crognale, & Kunde, 2012; Kunde, 2003; Kunde, Koch, & Hoffmann, 2004). The main result is that actions which produce compatible effects can be initiated faster than actions producing incompatible effects.

Partner reaction anticipations in joint action

As indicated above, the response-effect compatibility paradigm has been successfully transferred to settings in which another person's reactions to the subject's actions served as action effects (Müller, 2013b; Pfister, et al., 2013). However, it has also been shown that in the context of joint action such findings are by no means mandatory. For instance, Müller (2013a) used a more naturalistic setup in which multi-touch gestures to relocate virtual objects were followed by spatially compatible or incompatible partner reactions, i.e. gestures to either the same or a different object. In this rather complex task, no reliable compatibility effects were observed.

This raises the question to what degree influences of anticipated partner reactions on action control are possible in more naturalistic joint action scenarios. One reason to believe in the usefulness of joint action tasks as a tool to study partner reaction anticipations is the finding that "non-social" response-effect compatibility phenomena can also persist with more complex actions and effects (Janczyk, Yamaguchi, Proctor, & Pfister, in press; Kunde, Hoffmann, & Zellmann, 2002). On the other hand, joint compatibility paradigms tend to produce rather small effect sizes even in closely controlled settings (Atmaca, Sebanz, & Knoblich, 2011; Dolk et al., 2011; Pfister, Dolk, Prinz, & Kunde, 2014). Thus, partner response compatibility influences might be restricted to the performance of simple reactions such as button presses.

To gain more clarity about the generalizability of partner reaction anticipations, the goal of the present study is to provide a middle ground between simplistic paradigms (e.g. Pfister, et al., 2013) and rather complex tasks involving the joint manipulation of objects (Müller, 2013a). For that purpose, a multi-touch setup was used in which two participants successively performed simple swipe gestures on virtual objects.

Compatibility versus predictability

A second goal of this study is to differentiate between the influence of a partner reaction's compatibility with the subject's action and its predictability. It could be argued that incompatible partner reactions should not pose much of a problem for performance as long as they are predictable, because in this case it is possible for subjects to simply recode their mental representation of the partner's reactions (cf. Hommel, 1993). Indeed, when the context requires complementary actions, an observation of another person's actions that are dissimilar to one's own actions can result in an even stronger activation of the mirroring system than similar actions (Newman-Norlund, van Schie, van Zuijlen, & Bekkering, 2007). However, no studies so far have compared the relative impact of the compatibility and predictability of partner reactions on action planning processes.

There is some research on the compatibility versus predictability of another person's reactions with regard to other dependent variables. For instance, it has been shown that counter-imitation can generate what has been termed the "prosocial effects of imitation" (Catmur & Heyes, 2013). Favorable subjective ratings of the other person and the task as well as increased helping behavior were reported even when subjects' actions were followed by dissimilar actions presented on a display. However an elimination of the contingency between the subject's action and the subsequent presentation removed the effects. Thus, predictability was more important than compatibility. The present study aims to investigate whether the same is true for action planning.

Joint temporal compatibility

To investigate the generalizability of partner reaction anticipations and their dependence on compatibility versus predictability, a joint temporal compatibility paradigm was used. In a multi-touch setup, subjects changed the color 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 his speed either resembled the speed of the subject's gesture (compatible), was performed at the opposite speed (incompatible) or was unpredictable with regard to its speed.

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 partner reaction compatibility as an experimental manipulation has several benefits. First, actions can be used that are spatially confined and thus highly uniform across trials. Second, the partner reaction's compatibility is visible throughout the entire performance of a gesture and not only in its end state, increasing its potential impact on subjects' actions (cf. Müller, 2013a). Third, the feature constituting the compatibility is inherent in the action itself and not only concerns its target, as it is the case with spatial compatibility manipulations. This is likely to increase the involvement of action simulation processes. Together, these features should provide optimal conditions for partner reaction influences to be observable in the present paradigm. Therefore, it is hypothesized that subjects will be faster to initiate their actions in compatible blocks, when they know that the partner will respond with an action of similar speed.

The experiment also varied whether the subject's required movement speed was determined by an imperative cue or could be selected freely. This manipulation was included because in some studies action effects only influenced intentionally selected but not instructed actions (Herwig, Prinz, & Waszak, 2007). Thus, it is possible that partner reaction compatibility will reduce initiation times more strongly in free choice trials than when movement duration is instructed.

Besides initiation times which reflect action planning processes, it is also interesting to look at movement duration as a parameter of action execution. Following the logic of ideomotor theory and common coding (Hommel, et al., 2001; Prinz, 1997), anticipating a partner reaction that possesses certain features should activate the same feature codes in the subject. Thus, expecting a slow partner reaction should activate the cognitive codes for "slow", which might then spread to action execution and bias the subject's response to get slower as well. Conversely, expecting a fast reaction would bias the subject's movement to be performed faster. Together, this should result in an interaction of compatibility and required speed: In the compatible case (i.e. when the subject and partner perform movements of similar speed) fast movements should be even faster and slow movements should be even slower, whereas in the incompatible condition a speedup of slow movements and a slowdown of fast movements would be expected.

On the other hand, a study investigating temporal response-effect compatibility with automatic action effects did not find an interaction of required keypress duration and effect duration but only a main effect of effect duration (Kunde, 2003). Moreover, this main effect pointed in the opposite direction: Long effect tones resulted in a decrease of keypress durations and vice versa (contrast effect). Therefore, it is an open question whether compatible partner reactions will bias subjects' movement durations in the same or the opposite direction.

Methods

Subjects

Twenty-four students of the TU 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€. The experimenter acted as the partner for all subjects.

Apparatus and stimuli

The experiment was performed on a M2467PW multi-touch monitor (3M) with a display size of 24" and a spatial resolution of 1920 x 1080 pixels. Touch events were sampled at 180 Hz. The display was rotated horizontally so that it formed a table. The subject and partner were seated opposite to each other at the two long sides of the table. An overview of the stimulus material is provided in Figure 1. On the left side of the table from the subject's perspective, each participant had a pile of fifteen oval virtual objects per miniblock (see below), with a size of 350 x 100 pixels each. The subject's objects were colored green and the partner's objects were red. In the center of the table there was a grey board which served as the joint workspace for performing the swipe gestures to color the objects. The frame of this workspace was dark grey in the beginning of each trial and later changed its color as a cue to indicate the required speed (orange – fast, blue – slow, purple – free choice). During the object coloring 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 finger before performing their swipe gesture. Upon placing the finger on the starting position, that position turned red. 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 another grey board on which the objects had to be put after coloring.

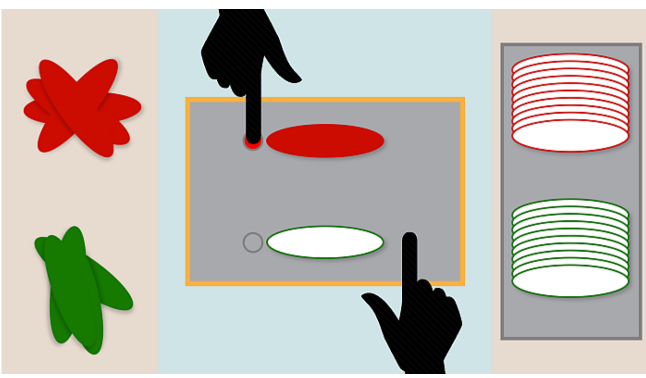

Figure 1: Stimulus example. The subject (lower hand) has just completed a gesture and the partner (upper hand) can start reacting.

Procedure

The experiment consisted of three parts between which the compatibility of partner reactions (compatible, incompatible, unpredictable) was varied. 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 colored 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. During the pre-phase, both participants moved one object from their pile to the workspace with a drag gesture, 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 (colored frame around the workspace) appeared and indicated the speed required from the subject. For fast trials, the object had to be colored 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 color cue appeared five times per miniblock, and 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 it automatically get stacked. The new trial started whenever the participants were ready and took the next object 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 (2.48 % of the data). The remaining data were submitted to 2 x 2 x 3 repeated measures ANOVAs with the factors choice (*instructed*, *free*), speed (*fast*, *slow*) and compatibility (*compatible*, *incompatible*, *unpredictable*). Post hoc comparisons were performed with Bonferroni correction.

Initiation times

The initiation time of a movement was computed as the latency between the onset of the color cue and the subject leaving the starting position. There were significant main effects of choice, $F(1,23) = 103.676$, $p < .001$, speed, $F(1,23) = 196.504$, $p < .001$, and compatibility, $F(2,46) = 4.749$, $p = .013$, as well as an interaction of choice and speed, $F(1,23) = 14.465$, $p < .001$. The interaction of choice and compatibility showed a non-significant trend, $F(2,46) = 2.577$, $p = .087$. No other interactions were significant, all Fs < 2, all ps $> .3$ (see Figure 2A). 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 time difference between slow and fast movements was more pronounced for instructed than freely chosen movements. Initiation times preceding compatible partner reactions (950 ms) were faster than those preceding incompatible reactions (1008 ms), p = .027, but did not significantly differ from initiation times in the unpredictable condition (970 ms), $p > .8$. The trend for an interaction of compatibility and choice reflected that the difference between compatible and incompatible initiation times only was significant in the free choice condition, p = .01, but not in the instructed condition, $p > .2$.

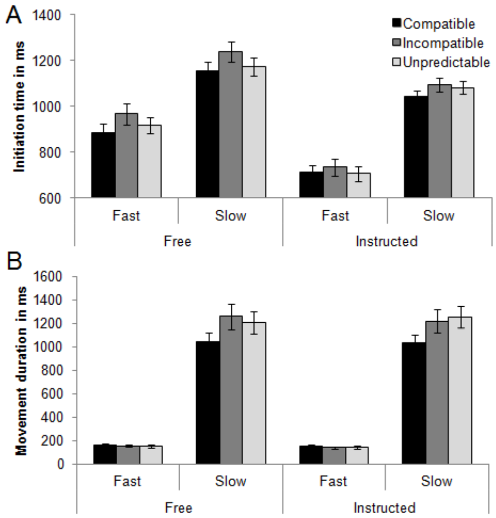

Figure 2: Initiation times (A) and movement durations (B) depending on choice, speed and compatibility.

Movement duration

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, $F(1,23) = 154.981$, $p < .001$, and compatibility, $F(2,46) = 5.994$, p = .005, as well as an interaction of compatibility and speed, $F(2,46) = 6.897$, $p = .002$. No other main effects or interactions were significant, all Fs < 3, all ps > .1 (see Figure 2B). Not surprisingly, fast movements took less time than slow movements (152 vs. 1167 ms). The main effect of compatibility indicated that movement durations were shorter in compatible than incompatible and unpredictable blocks, both ps < .03, whereas these two latter conditions did not differ from each other, $p > .9$. However, the interaction of compatibility and speed revealed that this time reduction in compatible relative to incompatible and unpredictable blocks was due to the slow movements only (1035 vs. 1237 and 1230 ms), both ps < .03, whereas for fast movements there were no significant differences between compatibility conditions (158, 148 and 150 ms), all ps > .1.

Error rates

A trial was included in the error analysis if the subject's movement did not conform with the currently instructed speed. Overall, error rates were very low (1.75 %). As errors were not possible in free choice trials, the ANOVA only included the factors speed and compatibility. There was a main effect of speed, $F(1,23) = 9.510$, $p = .005$, indicating that less errors were committed for fast movements than slow movements (.72 vs. 2.78 %). The main effect of compatibility was not reliable, $F(1,23) = 2.467$, $p = .096$. Whereas numerically errors were more frequent in compatible blocks than in incompatible and unpredictable blocks (2.75 vs. 1.50 vs. 1.00 %), none of the three conditions significantly differed from the others, all ps > .1. There was no interaction of speed and compatibility, $F < 1$.

Discussion

When we engage in joint actions with a partner, does the mere anticipation of that partner's reaction determine how we plan and execute our actions? To investigate the influence of temporal partner reaction compatibility, a joint multi-touch study was conducted in which participants manipulated objects with swipe gestures of varying speeds. An analysis of the movement initiation times revealed a performance benefit for situations in which the partner responded compatibly as opposed to incompatibly. The results are in line with two previous studies reporting influences of partner reaction compatibility (Müller, 2013b; Pfister, et al., 2013). Moreover, the present study extends these findings to a more naturalistic joint action setting. This suggests that the absence of reliable compatibility effects in the joint spatial compatibility task used by Müller (2013a) was not an inevitable consequence of using more naturalistic paradigms but probably can be traced back to particularities of the experimental setup.

A second extension of previous findings is the differentiation between influences of a partner reaction's compatibility and predictability. Initiation times were slowed down only in incompatible but not unpredictable blocks. This can be expected from a common coding perspective (Hommel, et al., 2001; Prinz, 1997) in which the mental representations of action effects (or partner reactions for that matter) use the same cognitive codes as action planning processes. As a consequence, anticipating an incompatible partner reaction should activate the corresponding movement features and thus impair the currently required movement. Instead, if no competing codes get activated in unpredictable blocks, no impairment should occur. Note, however, that although performance in the unpredictable condition was numerically more similar to that in the compatible than the incompatible condition, it did not statistically differ from either condition. To the degree that the unpredictable condition provides a suitable baseline, this might be taken to indicate that both costs and benefits contributed to the compatibility effects in the present study.

These results are not trivial, because previous research revealed that action effect influences were mostly due to a facilitation by compatible instead of an impairment by incompatible effects (Hommel, 2004). These findings suggest that the use of effect representations for action coding is at least partly strategic, and only occurs when they are helpful. On the other hand, there might be a genuine difference between social and non-social action effects, mirroring the higher impact of biological than non-biological stimuli in the study of automatic imitation

(Gowen & Poliakoff, 2012). However, before drawing any firm conclusions, the present result should be replicated.

Compatibility has contrastive effects on movement duration

In the movement durations there was a compatibility effect which was further modulated by speed: Subjects' slow movements were performed faster when followed by a compatible (i.e. also slow) partner reaction than by an incompatible (i.e. fast) or unpredictable reaction. In contrast, fast movements were not modulated by compatibility, perhaps because their very short durations of less than 200 ms on average did not leave much room for any adaptation. The speedup of slow movements by slow partner reactions is somewhat similar to the contrast effect reported by Kunde (2003) who showed that effect duration biased keypress duration in the opposite direction.

However, this does not necessarily mean that the underlying mechanism is the same. Whereas Kunde suggested an averaging of effect representations from different modalities (i.e. kinesthetic and auditory), this explanation is highly unlikely in the present study. This is because the time window of around 70 ms in which such averaging typically occurs (Aschersleben & Prinz, 1997) is clearly exceeded by the partner's initiation time of 542 ms on average. Alternatively, the movement duration result could reflect strategic processes. For instance, subjects might increase their effort to adhere to the instruction (or self-chosen plan) to perform a slow movement in the presence of distraction from the partner's reaction.

However, at present it would be premature to settle on any explanation because of an important confound in the present paradigm. As Pfister et al. (2013) noted, "it takes two to imitate", implying that both partners are susceptible to compatibility influences. Indeed, the duration of slow partner movements revealed a highly significant compatibility effect, $F(2,46) = 11.718$, $p < .001$, indicating that the partner also produced the fastest movements in compatible blocks (871 vs. 1017 and 999 ms), both *p*s < .005. This cannot directly affect subjects' slow movement durations by way of effect anticipation, because in incompatible blocks a slow subject movement was never followed by a slow partner movement. However, the speed difference may have resulted in a more general priming of speed, or even have set an implicit norm for what counts as a slow movement in a given block. Therefore, non-ideomotor accounts might explain the movement duration results. Future studies will have to test both accounts against each other, although this might require abandoning the joint action setup and use ostensive partners instead.

Why partner reactions are still valuable

The previous discussion highlighted the problem of reduced experimental control when using the reactions of a real human partner to study ideomotor influences on joint action. This might lead to the conclusion that investigations should be restricted to paradigms using simulated partner reactions such as pictures, videos or virtual agents (e.g. Kunde, Lozo, & Neumann, 2011; Pfeiffer, Timmermans, Bente, Vogeley, & Schilbach, 2012). Although this approach certainly has its own merits, it cannot replace real joint action tasks. Due to some characteristic differences between partner reactions and automatic action effects, joint tasks can extend our knowledge about effect anticipations.

First, partner reactions are not directly caused by the subject but by another intentional agent. While causal attributions are not a necessary condition for action effects to influence performance (Verschoor, Eenshuistra, Kray, Biro, & Hommel, 2011), it had not been investigated whether effect anticipations could be influential even in the clear absence of direct causal links to the action. This quest can be taken further by applying partner reactions which are not even indirectly caused by the subject's action but just happen to perfectly correlate with it, for instance due to environmental factors that either require the two participants to perform the same or different actions.

A second feature that differentiates partner reactions from automatic effects is their higher variability, both in terms of their latency and their manner of being executed. No two hand gestures are exactly the same. If they still have the power to influence action planning, this indicates that action-effect bindings can generalize to stimuli that are not identical. Testing the limits of this generalization by manipulating the variability of partner reactions will be an interesting topic for future research.

Finally, research in other joint action paradigms has highlighted the importance of studying real interactive tasks to examine the influence of other people's behavior. For instance, people simulate the actions of active interaction partners more strongly than the actions of persons that are merely observed (Kourtis, Sebanz, & Knoblich, 2010). Future studies will continue on this path by adding more interactivity and interdependence in the context of studying the impact of partner reactions.

Taken together, the compatibility of anticipated partner reactions can facilitate action planning even in more naturalistic joint tasks. The present study replicated previous findings from studies of response-effect compatibility, and extended them to a situation in which action effects were not directly caused by the subject but an interaction partner. How much of these findings can be explained by ideomotor theory versus more general priming accounts will have to be settled in future investigations.

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