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What or when? The impact of anticipated social action effects is driven by action-effect compatibility, not delay

Roland Pfister[1] · **Lisa Weller**[1] · **David Dignath**[2] · **Wilfried Kunde**[1]

Abstract Motor actions are facilitated if they are foreseeably being imitated rather than counterimitated by social partners. Such beneficial effects of anticipated imitation have been explained in terms of compatibility between one's own actions and their anticipated consequences. Previous demonstrations of these effects might alternatively be explained by consistently faster partner responses for imitative than for nonimitative actions, however. This study contrasts both explanations by using virtual coactors to disentangle the contributions of anticipated action-effect compatibility and anticipated action-effect delay. The data of two experiments support previous theoretical assumptions by showing that the effects of anticipated imitation are indeed driven by compatibility rather than delay.

Keywords Action control · Social interaction · Ideomotor theory · Action-effect compatibility · Delay

Whenever we move our body, we change our perception, be it that we feel, see, or perhaps hear how we move. Such perceptual consequences of one's own actions are not only relevant for deciding which action to perform but they are also functionally relevant for initiating the action in question. For example, it is easier to initiate a hand movement that reliably triggers a tool or a cursor to move into the same rather than the opposite direction (Chen & Proctor, 2013; Shin & Proctor, 2012; Müsseler, Kunde, Gausepohl, & Heuer, 2008). These findings are theoretically interesting, as they suggest that predictable movement consequences—*action effects*—might become part of the process of movement production itself. More specifically, ideomotor theory proposes that agents acquire bidirectional associations between one's own movements and the following effects. In order to initiate this movement again, the previous effects are anticipated, which in turn activates the corresponding motor patterns (see Shin, Proctor, & Capaldi, 2010, for a review).

Empirical evidence for the assumptions of ideomotor theory has been provided by numerous studies (e.g., Elsner & Hommel, 2001; Hoffmann, Lenhard, Sebald, & Pfister, 2009; Hommel, 1993; Kunde, 2001; Kunde, Hoffmann, & Zellmann, 2002; Pfister, Janczyk, Gressmann, Fournier, & Kunde, 2014; Wolfensteller & Ruge, 2011). A growing number of studies on the anticipation of action effects during action planning and initiation used action-effect (A-E) compatibility paradigms, in which participants perform speeded actions that foreseeably produce action effects in the environment. The employed actions and their effects can be represented on a common dimension (e.g., space, time), and they either share certain features on this dimension (A-E compatible condition) or they do not share these features (A-E incompatible condition). In the spatial domain, for instance, compatible action effects could occur on the same side as the action (i.e., a button press with the right hand may trigger an action effect on the right side of the computer screen), whereas incompatible action effects occur on the other side. Generally, participants respond faster when action effects are compatible rather than incompatible (Ansorge, 2002; Keller & Koch, 2006; Kunde, 2001, 2003; Pfister & Kunde, 2013; Pfister, Janczyk, Wirth,

Roland Pfister and Lisa Weller shared first authorship

✉ Roland Pfister
roland.pfister@psychologie.uni-wuerzburg.de

✉ Lisa Weller
lisa.weller@uni-wuerzburg.de

[1] Department of Psychology, Julius Maximilians University of Würzburg, Röntgenring 11, 97070 Würzburg, Germany

[2] Albert Ludwigs-University of Freiburg, Freiburg, Germany

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Dignath, & Kunde, 2014; Rieger, 2007; Yamaguchi & Proctor, 2011; Zwosta, Wolfensteller, & Ruge, 2013). Importantly, A-E compatibility influences response initiation although the effects are only present after the response has been executed. It is therefore reasonable to assume that action effects are indeed anticipated during action planning and initiation (Kunde, Koch, & Hoffmann, 2004).

Recent studies have begun to investigate whether effect-based action control also extends to the behavior of other agents as possible action effects—so-called sociomotor actions (Kunde, Weller, & Pfister, 2017; for corresponding empirical findings, see Flach, Press, Badets, & Heyes, 2010; Kunde, Lozo, & Neumann, 2011; Müller, 2016; Pfister, Dignath, Hommel, & Kunde, 2013). In the study of Pfister et al. (2013), two participants worked in pairs. One participant—the model—responded to an imperative stimulus with either a long or short button press. In different blocks, the other participant—the imitator—was either to imitate the model's response (i.e., to produce a compatible action effect) or to counterimitate the response (i.e., to produce an incompatible action effect). The model's reactions were faster in imitation (i.e., compatible) blocks compared to counterimitation (i.e., incompatible) blocks and as compared to blocks in which the imitator's response was unpredictable (for a replication and extension to joint object manipulation tasks, see Müller, 2016).

At first sight, these findings clearly indicate that the model anticipates the upcoming behavior of the imitator. More precisely, anticipation of the imitator's action seems to function as a retrieval cue for the model and facilitates action initiation in the imitation condition relative to the remaining conditions. This explanation is in line with previous work on A-E compatibility as reviewed above. However, due to the social nature of the employed task, compatibility of actions and action effects may not be the only explanation for the observed pattern of results. In line with previous studies on imitation (Bertenthal, Longo, & Kosobud, 2006; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Catmur & Heyes, 2011), the imitating participant also responded faster in the imitation condition than in the counterimitation condition so that the model could not only predict the upcoming response in each trial but could also predict whether the imitator would be rather fast or rather slow to emit his or her response. And, indeed, there are at least two lines of research to suggest that delayed action effects can slow down action initiation.

For one, recent findings suggest that the temporal interval between action and effect is represented in bidirectional action-effect associations (Dignath & Janczyk 2017; Dignath, Pfister, Eder, Kiesel, & Kunde, 2014; Haering & Kiesel, 2012; Kiesel & Hoffmann, 2004; Wirth, Pfister, Janczyk, & Kunde, 2015). In one study, participants performed a series of left and right key presses that predictably triggered an effect tone after a delay of 2 seconds in an initial acquisition phase (Dignath et al., 2014). In a following test phase, participants were presented with the previous effect tones and were instructed to respond with a spontaneously chosen key press. Following common findings on A-E learning, participants preferred acquisition-consistent choices, suggesting that they had acquired bidirectional A-E associations (Elsner & Hommel, 2001, 2004; Pfister, Kiesel, & Hoffmann, 2011). Acquisition-consistent choices, however, gave rise to slower responses compared to acquisition-inconsistent choices, suggesting that successful retrieval of the A-E associations also retrieved the associated delay. Arguably, recollecting the temporal duration between response and effect takes time and prolongs initiation of the response. In line with this interpretation, a direct comparison of responses that predictably triggered either immediate or delayed tone effects (50 ms vs. 2,000 ms action-effect interval) yielded faster responses for immediate than for delayed tones (Dignath et al., 2014, Exp. 3). Even though the difference between the imitator's reaction time (RT) in the imitation and counterimitation condition of previous studies was considerably smaller than the above-mentioned delays, anticipating slow versus fast responses of the imitator might at least partly account for the observed effects.[1]

For another, research on joint action suggests that working jointly on a task automatically leads to synchronization of the involved agents (Sebanz, Bekkering, & Knoblich, 2006). For instance, when two participants were given the opportunity to sit in a rocking chair while viewing each other, visual information of the other agent's rocking frequency alone led to spontaneous synchronization between both rocking movements. This synchronization even occurred if the chairs were designed to swing with different frequencies by default (Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007; for related discussions, see Bernieri & Rosenthal, 1991; Schmidt & Richardson, 2008). Assuming that agents also synchronize the timing of their actions with delayed consequences of their actions (Aschersleben & Prinz, 1997) suggests that the model in the studies of Pfister et al. (2013) and Müller (2016) might have responded slower in the counterimitation condition than in the imitation condition because he or she synchronized with the responding participant (cf. Watanabe, 2008; a similar explanation might be derived from reduced flow or fluency in the counterimitation condition).

In a first attempt to address the contribution of A-E delays to the effects of being imitated, Lelonkiewicz and Gambi (2016, Exp. 2) replicated the setup of Pfister et al. (2013) but

[1] The imitator's mean RTs in the imitation and counterimitation condition of Pfister et al. (2013) were 336 ms and 417 ms, respectively, corresponding to a difference of $\Delta RT = 81$ ms. Similar results were obtained in the three experiments of Müller (2016) ; $\Delta RT_{Exp.\ 1} = 54$ ms; $\Delta RT_{Exp.\ 2} = 86$ ms; $\Delta RT_{Exp.\ 3} = 67$ ms. The difference in A-E intervals used by Dignath et al. (2014), by contrast, amounted to 1,950 ms.

changed the task so that the imitator was now faster to counterimitate than to imitate the model participant.[2] This was achieved by precueing the correct response in counterimitation blocks but not in imitation blocks, which produced a notable effect on the imitator's RT ($\Delta RT = -356$ ms). As a consequence of this manipulation, the model participant now also responded faster in the counterimitation blocks, thus reversing the previously observed results (Müller, 2016; Pfister et al., 2013). Lelonkiewicz and Gambi attributed this finding to spontaneous temporal adaptation of both participants as described above, and they concluded that previous findings on the impact of A-E compatibility in social settings might be driven entirely by this mechanism.[3]

Even though these findings seem to support alternative explanations of the impact of anticipated social effects, at least three reasons suggest that the previously documented effects of anticipated imitation are indeed due to A-E compatibility and cannot be explained exclusively by increased delay or automatic tendencies for synchronization. For one, an impact of delay should especially affect the data if between-condition differences in delay are pronounced and therefore perceivable for the model. And indeed, the differences in delay were much more pronounced in the manipulation of Lelonkiewicz and Gambi (2016, Exp. 2) than in the natural variation observed in previous work (Pfister et al., 2013; Müller, 2016).

Second, if alternative explanations in terms of A-E delay hold, one would assume larger effects of anticipated imitation, the longer the delay associated with counterimitation. This association should be mirrored in a correlation of the effects for the model and the imitator across participants. Indeed, such a correlation emerged for the study of Lelonkiewicz and Gambi, whereas no such correlation emerged in previous experiments (Müller, 2016; Pfister et al., 2013).

Third, A-E compatibility effects were found with social stimuli when the effect stimuli were presented at constant and short delays. This held true for hand-shaking actions that triggered compatible or incompatible pictures of a responding hand on the screen (Flach et al., 2010), and also for facial actions (smiling or frowning) if these actions produced a picture of a smiling or frowning face (Kunde et al., 2011). Based on these observations, we argue that A-E compatibility likely is a critical factor for the impact of anticipated imitation, though a definitive test still needs to be carried out. This was the goal of the present experiments.

We therefore replicated the setup of previous experiments on anticipated imitation but had our participants interact with a virtual agent to maximize experimental control over A-E compatibility as well as over A-E delay (for similar approaches in studies on automatic imitation, see Longo & Bertenthal 2009; Longo, Kosobud, & Bertenthal, 2008). The virtual character had a humanoid appearance and his movements were animated so that bottom-up features would support a social representation of the coactor (Bailenson & Yee, 2005; Nowak & Biocca, 2003; Pan & Hamilton, 2015). Experiment 1 aimed for a conceptual replication of Pfister et al. (2013) and asked whether the effects of anticipated imitation would occur when the delay between model and imitator action is held constant across conditions. Experiment 2, then, contrasted the effects of compatibility and delay directly by combining both factors orthogonally.

Experiment 1

In Experiment 1, we investigated the influence of being imitated or counterimitated while controlling the delay between the model's action and the imitator's response. The participant's task was similar to the setting of Pfister et al. (2013). Accordingly, participants had to produce long or short button presses in response to imperative color stimuli, and their actions were followed by responses of an imitator. In different blocks, a virtual character displayed on the computer screen either imitated the participant's action or performed the alternative action. We predicted that the model would react faster in imitation blocks than in counterimitation blocks, even though the delay between action and effect (imitative or counterimitative behavior) was held constant in both conditions.

Method

Participants

Thirty-two participants from the University of Würzburg were recruited (mean age = 25.8 years, *SD* = 8.5, six male, five left-handed). An a priori power analysis based on the uncorrected effect size for anticipated imitation i.e., $\left(d_z = \frac{t}{\sqrt{n}} = \frac{t}{\sqrt{n}} = 0.89\right)$ suggested a sample size of 12 participants for a power of 1 - β = .80 (data taken from Pfister et al., 2013). We still chose to test additional participants because controlling for delays might decrease the effect size to an unknown extent (Lelonkiewicz & Gambi, 2016). All participants gave informed consent and received either course credit or monetary compensation for participation.

[2] Alternative explanations in terms of anticipated delay or temporal synchronization might be especially relevant for the designs of Pfister et al. (2013) and Müller (2016 , Exp. 3) because the participant's actions also differed with regard to temporal features (short vs. long), possibly drawing attention also to other temporal features of the task.

[3] Note that the results of Lelonkiewicz and Gambi (2016) do not necessarily indicate temporal adaptation but might equally be driven by anticipations of the to-be-expected A-E delay (Dignath et al., 2014). Both explanations, however, can be taken to suggest that A-E compatibility effects in social settings are at least confounded with the effects of A-E delay, or might indeed be explained entirely by one or both alternative explanations.

Stimuli and apparatus

Participants sat in front of a 17-in. monitor at a viewing distance of approximately 60 cm. They operated the *m* key of standard German QWERTZ keyboard, which was marked with a colored label. The experiment was programmed in E-Prime 2.0 (Psychology Software Tools Inc., Sharpsburg, PA, USA). Stimuli prompting participants' reactions appeared in the lower center of the screen, whereas the upper center of the screen showed a male virtual character who was displayed throughout the experiment (see Fig. 1; for a similar procedure, see Flach et al., 2010). Participants could see the upper body of the character as well as a table board and a black hemispherical button. During presentation of the imperative stimuli, a picture of the virtual character was displayed. This picture was replaced by videos that had the same start and end frame as the picture and showed the character doing either a short or a long button press. That way, participants got the impression that the virtual character was present throughout the whole experimental block. Videos and pictures of the virtual character and the environment surrounding the character were created with Poser 10 (Smith Micro Software Inc., Aliso Viejo, CA) and are available online (https://osf.io/xket7/). The course of the avatar's movements was identical in both videos, the short and the long button press, but the timing was different. The video of the short button press had a duration of 1,200 ms (consisting of 60 frames with a duration of 20 ms each). The avatar's arm movement started in the second frame (i.e., after 20 ms), the avatar touched the button 540 ms after video onset and pressed the button for 100 ms. The video of the long button press had a duration of 2,400 ms (consisting of 60 frames with a duration of 40 ms each). The arm movement also started with the second frame (i.e., after 40 ms), the avatar touched the button 720 ms after video onset, and button press lasted 840 ms.

Procedure

At the beginning of the experiment, participants were introduced to the virtual character, named Tim. They were informed that Tim's reaction depended on their reaction as well as the current block, and it was emphasized that they would have to work together with Tim throughout the experiment. Then, participants were allowed to practice the long and short key presses separately, without the virtual character on the screen.

In the actual experiment, each trial started with a white fixation cross, followed by an imperative stimulus that was presented until the end of the trial. The imperative stimulus was either a green or red rectangle, and participants had to respond to the color with either a short (1–150 ms) or long key press (200–600 ms). The assignment of colors to response duration was counterbalanced across participants. If participants responded correctly to the color stimulus, the virtual character in the upper half of the screen started to move. The character lifted his left arm and pressed the black button in front of him. Depending on the current block, the button press either corresponded to the participant's action (imitation condition; i.e., a long button press if participants had performed a long key press and short button press if participants had performed a short key press), or it did not correspond to the participant's action (counterimitation condition; i.e., long button press after short key press and vice versa). The videos of the character did not start immediately after participants' button press but only after a randomly chosen delay of 275 to 485 ms duration,[4] both in the imitation as well as in the counterimitation condition. That way, the character's movement timing was similar to the timing of natural agents, who cannot imitate or counterimitate immediately but need some time to process and prepare their own responses and who do not react equally fast in all trials. Still, the average delay was held constant across all trials for both conditions.

If participants responded incorrectly to the color stimuli or did not respond at all, an error message was displayed for 2,000 ms and the virtual character remained still. In addition, if participants' key presses did not meet the criteria for long or short key presses, a message was displayed telling the participants that the key press could not be classified, and a new trial started.

The experiment consisted of one imitation and one counterimitation block with 120 trials each (half of them demanding a long key press and half a short one). The first 10 trials of each block were considered practice and were not included in the analyses. The order of blocks was counterbalanced across participants.

Results

Four participants struggled to perform key presses that met the criteria of long or short key presses and thus produced many trials of key presses with false durations (>15%). We therefore excluded the data of these participants from further analysis. For RT analysis of the remaining participants, we excluded all trials with commission errors (i.e., a long key press when a short key press was required or a short key press when a long

[4] As upper and lower boundary, we used the first and third quartile of the imitator's RT distribution in Experiment 1 of Pfister et al. (2013); collapsed across conditions. This delay was used to match the virtual character's reactions with human RTs in a comparable experimental setting. Due to an error in this computation, the upper boundary was 27 ms higher than intended. Fortunately, this error does not confound the results because the higher boundary applied to both, the imitation and the counterimitation condition (with mean delays being 380 ms in both conditions).

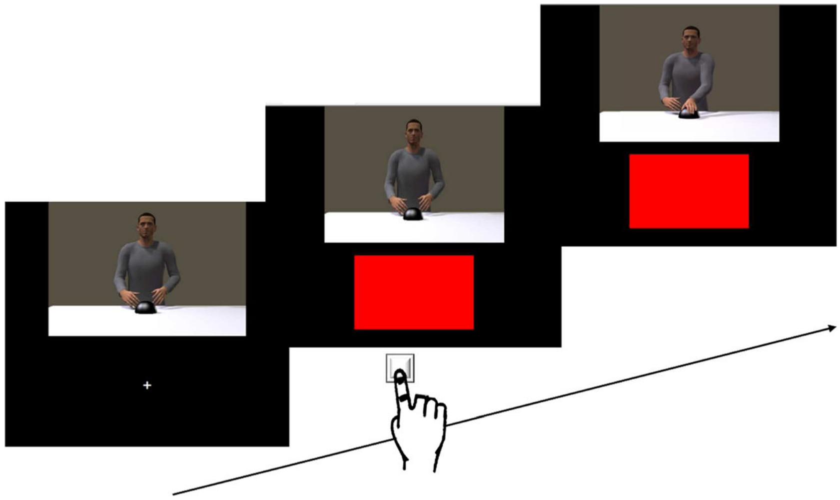

Fig. 1 Setup of Experiment 1. Participants interacted with a virtual agent, "Tim," who either imitated or counterimitated the participant's actions. Each trial started with a white fixation cross for 1,000 ms, followed by a red or green rectangle, which prompted participants to respond with either a long or short key press. After a variable delay, the virtual character started to move and performed a button press. In different blocks, the duration of the button press either corresponded to the participant's key press (imitation condition) or had the opposite duration (counterimitation condition). The mean delay between the participant's action and the response of the virtual agent was constant across conditions. (Color figure online)

key press was required; 2.0%), erroneous reactions that did not fall within the boundaries of short or long key presses (6.8%) and all trials following erroneous trials from analysis. We further removed outliers from the analysis, with outliers being defined as RTs that deviated more than 2.5 standard deviations from the corresponding cell mean, calculated separately for each participant and condition (2.6%). For error analysis, only errors of commission were included; omissions and key presses that did not meet the criteria of long or short key presses were not considered. For statistical analysis of RTs and error percentages, we conducted repeated-measures analyses of variances (ANOVAs), with the factors imitation condition (imitation vs. counterimitation) and response duration (short key press vs. long key press).

Figure 2 shows the participants' RTs in imitation and counterimitation blocks separately for short and long key presses. As expected, participants initiated key presses faster when they were to be imitated rather than counterimitated, $F(1, 27) = 7.06$, $p = .013$, $\eta_p^2 = .207$. Additionally, participants were faster to initiate short key presses compared to long key presses, $F(1, 27) = 7.06$, $p = .013$, $\eta_p^2 = .207$, and these main effects were additive, as suggested by a nonsignificant interaction, $F(1, 27) = 0.36$, $p = .551$, $\eta_p^2 = .01$.

In imitation blocks, participants committed on average 2.1% errors for short key presses and 2.6% errors for long key presses. In counterimitation blocks, the percentage of errors was 1.9% for short key presses and 1.7% for long key presses. Error rates did not differ between conditions; the main effect of imitation was not significant, $F(1, 27) = 2.05$, $p = .164$, $\eta_p^2 = .071$, and neither were the main effect of response duration and the interaction (both Fs < 1).

Discussion

In Experiment 1, we investigated whether being imitated rather than counterimitated facilitates action planning when confounding effects of different A-E delays are controlled for. This was indeed the case: Participants responded faster when the virtual character would perform the same rather than the opposite movement in response to the participant's action. Participants also took longer to

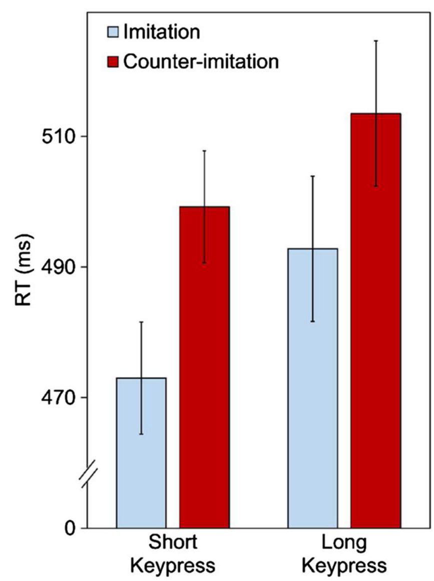

Fig. 2 Mean reaction times (RTs) for Experiment 1. Participants responded faster when they were to be imitated rather than counterimitated. *Error bars* represent standard errors of paired differences for the comparison of imitation and counterimitation, computed separately for short and long key presses (Pfister & Janczyk, 2013). (Color figure online)

initiate long compared to short key presses, mirroring previous findings (Klapp, 1995; Kunde, 2003; Kunde & Stöcker, 2002; Müller, 2016).

It should be noted that descriptions in terms of *same* and *opposite* actions refer exclusively to the relative timing of both movements (short vs. long), and they do not extend to absolute response durations or further spatiotemporal characteristics of the movements. This view is in line with common theoretical notions of dimensional overlap (Kornblum, Hasbroucq, & Osman, 1990): Both, actions and effects can be differentiated in the temporal domain into a shorter option and a longer option. Selecting and initiating the shorter response option is therefore facilitated when it contingently produces the shorter rather than the longer effect, and the opposite holds true for the longer response option. In this regard, it does not matter whether action and effect are both movements with certain durations (as in Experiment 1) or whether long and short actions trigger arbitrary tones of a relatively long or a relatively short duration (Kunde, 2003; Pfister, Pfeuffer, & Kunde, 2014). In all cases, compatible action-effect relations help the agent to retrieve the intended motor patterns, whereas incompatible action-effect relations counteract efficient retrieval. The present findings therefore suggest that A-E compatibility affects action planning in social settings even when controlling for confounding influences of A-E delay (Lelonkiewicz & Gambi, 2016). Experiment 2 went one step further and pitted both, A-E compatibility (imitation vs. counterimitation) and A-E delay, directly against each other.

Experiment 2

In Experiment 2, we manipulated orthogonally whether participants were imitated or counterimitated and whether the action effect followed after a long or short delay. The duration of long and short delays was taken from the data of the real interaction partners in Pfister et al. (2013).

We further used Experiment 2 to extend previous approaches to anticipated imitation to another type of behavior rather than the timing of (short and long) actions. We therefore adopted an experimental setup that is commonly used in the literature on motor priming (Bertenthal et al., 2006; Brass et al., 2000). Participants had to lift either the index or the middle finger of their right hand in response to imperative color stimuli. This movement was imitated or counterimitated by a virtual hand on the computer screen. In different blocks, the hand either lifted the same finger as the participant or the opposite finger, and the delay between the participant's reaction and the action of the virtual character was either long or short. Another reason for changing the type of behavior was that the videos of long and short button presses used in Experiment 1 differed with respect to the onset of the movement as well as the onset of the button press. These differences were eliminated in Experiment 2.[5] Because the changes in Experiment 2 rendered the action effects less salient than the effects of Experiment 1, we further included catch trials in the experiment to ensure that participants paid attention to the action effects.[6]

Method

Participants

Sample size was slightly increased to improve power for detecting also a possible influence of A-E delays and we recruited 48 participants (mean age = 26.8, *SD* = 7.1, 13 mal, two left-handed). All participants gave informed consent prior to the experiment and received either course credit or monetary compensation for participation.

Stimuli and apparatus

Participants sat in front of a 17-in. monitor at a viewing distance of about 60 cm and responded on a standard German QWERTZ keyboard with the keys *n*, *m* and *j*. In the center of the screen, a female left hand was displayed throughout the experiment (see Fig. 3). Imperative stimuli prompting the participants' responses (a blue or red rectangle) were superimposed between the index and middle finger of the hand.

To create the impression that the hand remained on the computer screen throughout the experiment, a picture of the hand in resting state (all fingers on the ground) was displayed during presentation of the imperative stimuli and intertrial interval (ITI). After the participants' reaction, a video of the moving hand was displayed (consisting of 40 frames with a duration of 33 ms each). The first and last frame of this sequence was identical to the picture presented during presentation of the imperative stimuli and ITI. As in Experiment 1, pictures and videos were created with the software Poser 10 and stimulus presentation was controlled by E-Prime 2.0.

[5] We thank Romy Müller for drawing our attention to this issue.

[6] We used the same experimental setup as in Experiment 2 without catch trials in a pilot study and found no effects of imitation and counterimitation. Because imitation and counterimitation affected participants' responses in Experiment 1, we concluded our experimental setup was not able to measure these effects. Since the movement of a single finger is not as distinct as a movement of the whole arm, we assumed that participants might not have paid sufficient attention to the movement of the hand (for a similar discussion, see Janczyk, Yamaguchi, Proctor, & Pfister, 2015; Müller, 2016; Wirth, Pfister, Brandes, & Kunde, 2016).

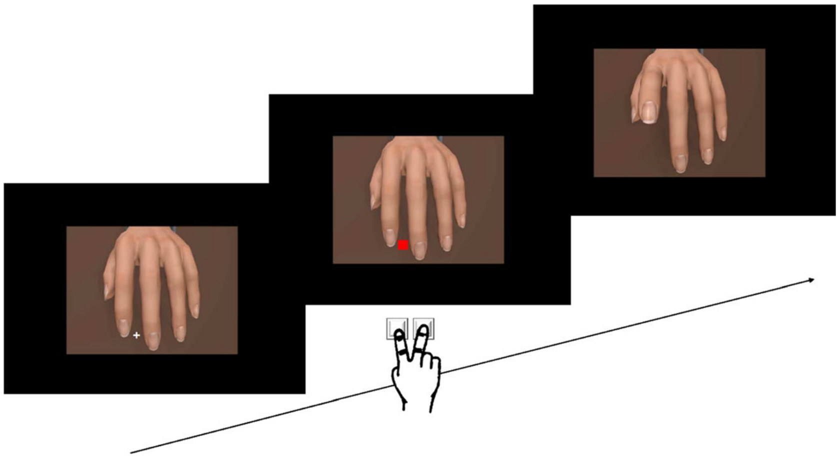

Fig. 3 Setup of Experiment 2. Participants lifted either the index or the middle finger of their right hand, and this movement was imitated or counterimitated by a virtual hand on the computer screen. Each trial started with a white fixation cross for 500 ms, followed by a red or blue rectangle that occurred for 200 ms. Participants responded to the color by lifting either the index finger or the middle finger of their right hand. If participants responded correctly, the virtual hand lifted its index or middle finger. In different blocks, either the same finger as the participant's finger was lifted (imitation condition) or the opposite finger (counterimitation condition). Additionally, the delay between the participant's reaction and the start of the finger movement was either short (336 ms on average) or long (417 ms on average). The experiment consisted of four blocks: One imitation block with short action-effect delays, one imitation block with long action-effect delays, and two counterimitation blocks, one with each delay. (Color figure online)

Procedure

At the beginning of the experiment, participants were introduced to a female virtual character, named Sophie, including a picture of the head and upper torso. Participants were informed that they would see Sophie's hand throughout the experiment and that Sophie's reaction would depend on their reaction and the current block. After that, participants completed seven practice trials and were made familiar with the catch trials (see below) before the actual experiment started.

During the experiment, participants placed the index and middle finger of their right hand on the *n* and the *m* key of the keyboard respectively and responded to imperative stimuli by lifting one finger, thus, releasing the corresponding key. As imperative stimuli, a red and a blue rectangle (with a length and width of approximately 20 mm) were used, and the assignment of colors to fingers was counterbalanced across participants. Each trial only started when participants pressed and held down the *n* and *m* key. Only then, a white cross appeared on the screen for 500 ms. Next, a red or blue rectangle was displayed for 200 ms, prompting participants to lift either their index or middle finger. If participants responded correctly, the hand started to move and lifted its index or middle finger. After the movement was finished, the hand remained still for 1,000 ms before the next trial started.

In different blocks, the finger movement of the hand on the screen either corresponded to the participant's response (imitation condition, i.e., the index finger was lifted if participants had lifted the index finger and vice versa) or it did not correspond to the participant's response (counterimitation condition). Additionally, the delay between the participant's response and the start of the hand movement was either short (319 to 353 ms) or long (391 to 443 ms) in different blocks.[7] Thus, the experiment consisted of four blocks, two imitation blocks (one with a short and one with a long delay) and two counterimitation blocks (one with a short and one with a long delay). Block order was randomized across participants. Each block consisted of 120 trials, and the first 10 trials of each block were considered practice and were not included in the analyses.

If participants lifted the wrong finger in response to the imperative stimuli, the word *Fehler* (German for *error*) was displayed for 1,000 ms. If participants released one or both keys too early (before the presentation of the imperative stimulus), the error message was also displayed, and participants had to press the keys *n* and *m* and hold them down before a next trials was started. Errors of these latter types were not used for analysis.

To ensure that participants paid attention to the movement of the hand, we implemented catch trials. In catch trials, the delay between the participant's response and hand movement was prolonged by 1,000 ms. Participants had to detect the late onset of the hand movement by pressing the *j* key. Each trial

[7] For Experiment 2, we aimed at using short versus long delays that corresponded precisely to the mean delay in the imitation and counterimitation condition of Pfister et al. (2013). Because the range of these delays was rather limited ($RT_{CounterImitation} = 417$ ms, $RT_{Imitation} = 336$ ms; as noted in the introduction), we decided to implement considerably less trial-to-trial variation to allow for clearly separated intervals. Instead of the interquartile ranges, we therefore sampled the delays from an interval of mean delay (i.e., the imitator's RT) ± 1 standard error of the mean delay across participants.

had a 1 in 20 chance to become a catch trial (determined randomly at the beginning of the trial), though the first 30 trials of each block were never used as catch trials. If participants responded correctly on catch trials, a message was displayed (*Sehr gut!*, German for *Well done*), and if they missed the catch trial, a warning message was displayed (*Achte auf Sophies Reaktionen*!, German for *Pay attention to Sophie's responses!*).

Results

One participant detected none of the catch trials. We excluded the data from this participant from all analyses because apparently the participant had not paid attention to the hand movements. For RT analysis, we excluded trials with errors (mean percentage of errors = 4.0%) and all trials following those trials, as well as trials following catch trials. Furthermore, we excluded all trials deviating more than 2.5 standard deviations from their cell mean, calculated separately for each participant and condition (2.4%).

For statistical analysis of RTs and error percentages, we conducted repeated-measures ANOVAs, with the within-subjects factors imitation condition (imitation vs. counterimitation) and delay (long vs. short).

Participants' RTs for each condition are shown in Fig. 4. A significant main effect of imitation indicated that participants initiated button presses faster when their responses were imitated rather than counterimitated, $F(1, 46) = 4.25$, $p = .045$, $\eta_p^2 = .085$. We found neither a significant main effect of delay, $F(1, 46) = 0.15$, $p = .702$, $\eta_p^2 = .003$, nor a significant interaction of imitation and delay, $F(1, 46) = 0.22$, $p = .644$, $\eta_p^2 = .005$.

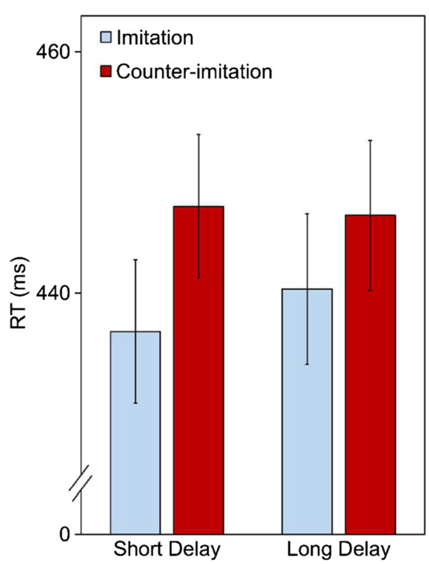

Fig. 4 Mean reaction times (RTs) for Experiment 2. Participants responded faster when they were imitated rather than counterimitated, irrespective of the delay between participants' actions and the imitative behavior. *Error bars* represent standard errors of paired differences for the comparison of imitation and counterimitation for short and long delays separately (Pfister & Janczyk, 2013). (Color figure online)

Participants committed on average 3.8% errors in the imitation block with short delays and 3.6% errors in the imitation block with long delays. In counterimitation blocks, the percentage of errors was 3.7% for the block with short delays and 4.0% for the block with long delays. Percentages of errors did not differ significantly between conditions; neither the main effects of imitation and delay reached significance, both Fs < 1, nor did the interaction of imitation and delay, $F(1, 46) = 1.23$, $p = .273$, $\eta_p^2 = .026$.

The analysis of the catch trials showed that participants detected on average 72.5% ($SD = 19.7$) of the catch trials. To test whether detection performance differed between conditions, we computed the percentage of detected catch trials for each participant and condition and conducted a repeated-measures ANOVA, with the within-factors imitation condition (imitation vs. counterimitation) and delay (long vs. short). One additional participant had to be excluded from this analysis because, by chance, there were no catch trials available for one block (because each trial of the experiment only had a 1 in 20 chance to be chosen as catch trial, it was possible to have blocks without any catch trials). In imitation blocks, the remaining participants detected 75.8% of the catch trials in blocks with short delays and 75.9% in blocks with long delays. In counterimitation blocks, 67.3% (short delays) and 70.8% (long delays) of the catch trials were detected. A main effect of imitation indicated that participants detected more catch trials in imitation blocks relative to counterimitation blocks, $F(1, 45) = 4.18$, $p = .047$, $\eta_p^2 = .085$. The main effect of delay was not significant and neither was the interaction of imitation and delay (both Fs < 1).

Discussion

In Experiment 2, we investigated whether responding would be facilitated when participants were being imitated rather than counterimitated and when A-E delays were short rather than long. In line with Experiment 1, participants' responses were facilitated when they were imitated rather than counterimitated. The A-E delay, by contrast, had no influence on response initiation. Furthermore, participants detected unexpectedly delayed responses of the virtual character (as in the catch trials) more frequently when they were imitated rather than counterimitated. We will get back to this finding in the general discussion.

General Discussion

The present experiments investigated whether previous findings on the impact of anticipated imitation on action planning and initiation were driven by A-E compatibility or by the delay between the model and the imitator action. Anticipated imitation still affected action control when the delay was held constant (Experiment 1). Furthermore, when combining A-E compatibility orthogonally with similar delays as in previous work (Pfister et al., 2013), RTs were only affected by compatibility whereas delay did not affect performance notably (Experiment 2).

These results are in line with common theoretical assumptions that any response-contingent event may be exploited for effect-based action control, be it an event in the physical or in the social environment (e.g., Hommel, 2009, 2013). The results further highlight a domain of social interaction—or joint action—that has received only limited attention from empirical studies. Typical studies on joint action focus on aspects such as joint performance of the same task or adaptation of the participant's own behavior to the observed behavior of others (e.g., Atmaca, Sebanz, & Knoblich, 2011; Böckler, Knoblich, & Sebanz, 2012; Pfister, Dolk, Prinz, & Kunde, 2014; Sebanz, Knoblich, & Prinz, 2003; Stenzel & Liepelt, 2016). The current study, by contrast, highlights situations in which the behavior of one agent prompts another agent to respond in a certain way. It is currently not clear whether or not these latter situations are represented similarly to situations in which two agents perform simultaneously or in which one agent adapts to others. Research on motor priming, for instance, has shown that spatial compatibility as well as imitative compatibility both prime corresponding actions; that is, left stimuli prime responses to the left, and observed movements of an index finger prime responses with the index finger (e.g., Boyer, Longo, & Bertenthal, 2012; Catmur & Heyes, 2011). Whether or not this dissociation also holds for the impact of anticipated imitation remains to be addressed.

A further worthwhile observation is that participants detected unexpectedly delayed action effects more accurately when they were consistently imitated rather than counterimitated. This finding may mirror a sustained inhibition of conflicting information (and/or the associated delay) as has been observed in studies on conflict adaptation (e.g., Melcher et al., 2015; Wendt, Luna-Rodriguez, & Jacobsen, 2012) and negative priming (Frings, Schneider, & Fox, 2015; Kane, May, Hasher, Rahhal, & Stoltzfus, 1997; Tipper, 2001). This finding is also consistent with the observation that incompatible action effects are generally harder to monitor than compatible action effects as revealed by increased dual task costs (Wirth, Janczyk, & Kunde, 2016).

In contrast to the compatibility of one's own actions and resulting actions of a social partner, the delay between an action and its effects did not influence action initiation in the current setting. This finding seems to contradict the idea that information about the temporal interval between action and effect is integrated into action plans (Dignath et al., 2014; Kiesel & Hoffmann, 2004). One critical difference to previous studies is that the delays in the present experiments were not constant but variable, which could counteract integration of temporal information about action-effect relations into action plans. This possibility remains to be addressed by further empirical work. Alternatively, however, this observation may also be taken to suggest a negligible role of A-E contiguity for the representation of other agents' behavior as long as the delay does not exceed a certain threshold (Lelonkiewicz & Gambi, 2016) and/or the task does not require precise temporal coordination between agents (e.g., Kourtis, Sebanz, & Knoblich, 2010). This speculation receives support from the relatively low accuracies of the detection task in Experiment 2 (pending around 72% on average) and appears to have high face validity because certain delays are a necessary feature of social interaction (because other agents will always require some time to process our actions and respond correspondingly). Due to the limited range of A-E delays, however, this speculation can only be verified against empirical investigations that address the impact of contiguity in social interactions more directly (e.g., by using methods similar to Lelonkiewicz and Gambi but opting for a more fine-grained manipulation of A-E delays).

What can be concluded with certainty is that previous findings of the impact of anticipated imitation do reflect an impact of the compatibility between one's own actions and the anticipated responses of social partners. The current results thus highlight that effect-based action control does incorporate also the social consequences of one's own actions.

Compliance with ethical standards

Ethical approval All procedures were in accordance with the ethical standards of the institutional ethics committee and with the 1964 Helsinki declaration and its later amendments.

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Data availability Stimulus materials, raw data, and analysis scripts are available on the Open Science Framework (https://osf.io/xket7/).

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