American Psychological Association

Journal of Experimental Psychology:
Human Perception and Performance

0096-1523/19/$12.00

2019, Vol. 45, No. 8, 1104–1118
http://dx.doi.org/10.1037/xhp0000658

Sociomotor Actions: Anticipated Partner Responses Are Primarily Represented in Terms of Spatial, Not Anatomical Features

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The sociomotor framework proposes that people can represent their actions in terms of the behavior these actions evoke in others, so that anticipating the behavior of others triggers own actions. In social interactions, such as imitation, it thus highlights the acting model rather than the responding person. In line with this idea, motor actions are facilitated if they are foreseeably imitated rather than counterimitated by a social partner. In the present study, we investigate how exactly another's behavior is represented in such sociomotor actions. The effect of being imitated can be explained by two distinct forms of compatibility between model and imitator actions: correspondence of anatomical features (imitative compatibility) and correspondence of spatial features (spatial compatibility). Both types of features often go hand in hand, though research on motor priming shows that spatial and anatomical features of other's actions are represented independently. We therefore investigated to which degree the benefit of anticipated imitation is caused by spatial or imitative compatibility. Across 5 experiments, we found that only spatial compatibility of the imitator's behavior influenced the model's actions, while imitative compatibility had no influence. Actors thus seem to represent actions of their social partners mainly in terms of nonsocial, spatial features.

Public Significance Statement

Humans tend to imitate the behavior of other social partners, which comes with numerous positive effects for the imitating person, as well as for the person being imitated. For instance, previous research has shown that actions are facilitated when they are foreseeably being imitated by another person. This means that our actions are influenced by another person's anticipated behavior even before the other actually acts. Here, we investigate what aspects of another person's behavior are represented in such anticipations. Our results show that we are strongly influenced by the physical location at which another person will be reacting, whereas anatomical features of another's actions—for instance, if the person will react with the left or the right arm—are disregarded. These findings suggest a surprisingly similar representation of anticipated action consequences in the social and nonsocial environment.

Keywords: imitation, ideomotor theory, sociomotor actions, spatial compatibility, imitative compatibility

Whenever we move, we inevitably produce perceptual effects. For instance, if we knock on a door, we produce a knocking sound, together with a changed feeling of the hand and a certain visual perception. Effect-based ("ideomotor") models of human action control propose that these effects of our actions are essential for initiating goal-directed actions. More precisely, ideomotor models assume that people acquire bidirectional associations between their movements and the following perceptual effects. These associations can then be used for action control: Anticipation of the effect automatically activates the corresponding motor patterns for the movement. Thus, if we want to knock on a door, anticipation of the knocking sound will activate the knocking motion. Numerous studies have accumulated evidence to support this ideomotor account of action control (e.g., Elsner & Hommel, 2001; Kunde, 2001; Pfister, Janczyk, Gressmann, Fournier, & Kunde, 2014; Riechelmann, Pieczykolan, Horstmann, Herwig, & Huestegge, 2017; Wolfensteller & Ruge, 2011; see Shin, Proctor, & Capaldi, 2010 for a review).

Our actions, however, not only produce perceptual effects in the inanimate environment, but they can also elicit a certain behavior in other people. In social interactions, for instance when jointly performing a task with someone else, our actions directly and foreseeably affect the behavior of other people. Thus, the behavior of other people can be an effect of our action, just like the inanimate effects of our actions. Importantly, recent formulation of

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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effect-based models of action control have emphasized that any action-contingent event can be used for action control (e.g., Hommel, 2009, 2013). It has therefore been proposed that anticipating the behavior of another person can also activate the associated motor pattern and that effect-based action control thus extends to actions that consistently change other people's behavior, so-called sociomotor actions (Kunde, Weller, & Pfister, 2018; for corresponding empirical studies, see, e.g., Flach, Press, Badets, & Heyes, 2010; Kunde, Lozo, & Neumann, 2011; Müller, 2016; Müller & Jung, 2018; Pfister, Dignath, Hommel, & Kunde, 2013). Research on such sociomotor actions focuses on a specific aspect of social interactions, that is, when the behavior of one person prompts another person to act in a certain foreseeable way.

Strong support for the influence of anticipated action effects (both, inanimate and social) on action control comes from studies using action-effect (A-E) compatibility paradigms. In these setups, participants perform speeded actions that trigger predictable effects. Importantly, these actions and their effects can be either compatible or incompatible to each other, that is, actions and effects either do or do not share features in a certain dimension (e.g., space or time). For instance, compatible action effects could occur on the same side as the action (i.e., a key press on the right producing an effect on the right side of the screen), whereas incompatible action effects would occur on the other side as the action. Participants typically generate actions more quickly when these actions (foreseeably) produce compatible rather than incompatible effects. As the effects are only presented after participants' actions, it is justifiable to assume that effects are anticipated and thus influence action planning and initiation (Ansorge, 2002; Kunde, 2001, 2003; Kunde, Koch, & Hoffmann, 2004; Pfister, Janczyk, Wirth, Dignath, & Kunde, 2014; Rieger, 2007; Yamaguchi & Proctor, 2011).

With regard to compatibility, sociomotor actions stand out compared to actions with inanimate action effects, because actions and action effects (the behavior of others) can have a unique degree of similarity. This is the case if actor and following person use the same effectors to produce the same behavior (Kunde et al., 2018). In the study by Pfister et al. (2013), for instance, two participants worked together in a social A-E compatibility design. One participant (the model) had to generate a long or short key press according to an imperative stimulus. The other participant (the imitator) had to either repeat the same long or short key press (the model was thus foreseeably imitated) or perform exactly the opposite key press (the model was thus foreseeably counterimitated). For one, the imitator[1] responded faster in the imitation condition compared to the counterimitation condition, replicating previous results on automatic imitation (e.g., Bertenthal, Longo, & Kosobud, 2006; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Stürmer, Aschersleben, & Prinz, 2000). More importantly for the sociomotor framework, there was also an A-E compatibility effect; that is, the model generated actions more quickly when foreseeably being imitated rather than being counterimitated by the other person. This observation suggests that the model's anticipation of the other person's behavior retrieves to some extent the very same behavior in the model. This is helpful when the other's anticipated action and the requested own action match (as in the imitation condition) but detrimental when they mismatch (as in the counterimitation condition; see also Müller, 2016; Pfister, Weller, Dignath, & Kunde, 2017).

Even though these results indicate that the model anticipates the imitator's actions, it remains unclear how exactly sociomotor actions are represented. Research on motor priming (i.e., the imitator's perspective of imitation) has identified two separate features that are both relevant for imitation. For one, observing the model prompts the imitator to respond with a homologous effector (e.g., key press with index vs. middle finger). For another, it prompts the imitator to respond to the same spatial location (e.g., right vs. left key). These factors have been called "imitative compatibility" and "spatial compatibility," respectively. While spatial compatibility is arguably domain general and shared for social and nonsocial stimuli, imitative compatibility is tied to the fact that model and imitator share homologous body parts (Bertenthal et al., 2006; Boyer, Longo, & Bertenthal, 2012; Catmur & Heyes, 2011; see Heyes, 2011, for a review, and Cracco et al., 2018, for a recent meta-analysis).

The same distinction between spatial and imitative compatibility can be made for the model's side of imitation, and both factors might contribute to the facilitative effect of being imitated (Pfister et al., 2013). In other words, social action effects do not only coincide with an agents' action in terms of physical parameters but they also come with the potential of involving homologous body parts (also labeled "sociomotor similarity" by Kunde et al., 2018), and agents may represent either spatial or anatomical (i.e., imitative) features of anticipated responses to control their own actions.

Previous research makes a claim for both possibilities. Studies using nonsocial A-E compatibility settings revealed that spatial compatibility is involved in action control (e.g., Kunde, 2001; Kunde, Pfister, & Janczyk, 2012; Pfister, Kiesel, & Melcher, 2010) and even suggest that one's own actions are primarily represented in terms of spatial features rather than anatomical features in nonsocial situations. For instance, when participants were asked to respond with crossed hands, that is, with the left index finger placed on a right response key and the right index finger placed on a left response key, anticipating a left action effect was found to prime mainly the left response key and not the left hand (Hoffmann, Lenhard, Sebald, & Pfister, 2009; Hommel, 1993; Pfister & Kunde, 2013). Previous research on action control in the nonsocial environment would therefore suggest that, in a social context, agents also represent spatial features of anticipated responses to control their own actions. However, action effects in the nonsocial environment do not comprise anatomical features, that is, they come with low sociomotor similarity to the body movements that the agents produce themselves (Kunde et al., 2018). Social action effects, on the other hand, come with the potential of involving similar anatomical features and findings from nonsocial action effects might therefore not be transferable to social action effects. Research on motor priming shows that imitative features of another person's actions can influence own actions (Bertenthal et al., 2006; Boyer et al., 2012). In line with these results, imitative features of another person's action might also be represented to control own actions in a social context. Thus, whether or not effect-based action control in social settings exploits anatomical features of anticipated actions is an open question. Answering this

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[1] We call this person "imitator," but note that he or she literally imitated the model only in the imitation condition but counterimitated the model in the counterimitation condition.

question, in turn, is critical for a precise theoretical understanding of action representation and action control in social situations.

We adopted tried-and-tested experimental methods to disentangle the roles of spatial and imitative compatibility for anticipated imitation. To this end, we used an imitation setup where two participants faced each other and were asked to perform finger-lifting actions with either their index or their middle finger. The model always used index and middle finger of the right hand to respond to imperative color stimuli and the imitator followed by imitating or counterimitating the model's action in different blocks. The critical manipulation was whether the imitator used the left or right hand: If the imitator uses the left hand, imitative and spatial compatibility are confounded, because a model action with the left (index) finger will trigger an imitator response with the index (left) finger in imitation trials and a response with the middle (right) finger in counterimitation trials. If the imitator uses the right hand, however, a model action with the left (index) finger will trigger a response with the left (middle) finger in one condition and a response with the right (index) finger in the other condition. Thus, spatial and imitative compatibility are pitted against each other (Bertenthal et al., 2006).

In five experiments, we used this setup to disentangle the influence of spatial and imitative compatibility in sociomotor action control. With Experiment 1, we established that a robust influence of being imitated can indeed be found with finger-lifting actions. In this initial experiment, we opted to confound imitative and spatial compatibility to replicate previous setups that used long versus short model actions (Pfister et al., 2013). In Experiment 2, we then pitted spatial and imitative compatibility against each other. If imitative compatibility is a relevant feature for action control, spatial compatibility effects should be reduced as compared to Experiment 1 or even nonexisting in this experiment. In the last three experiments, we manipulated spatial and imitative compatibility orthogonally within subjects by using both left and right hands in different blocks. To that end, participants were imitated by a virtual avatar in Experiment 3 and a real person in Experiment 4, while Experiment 5 directly compared these two settings. We expected an independent benefit of both spatial compatibility (reacting on the same rather than the other side as the imitator) and imitative compatibility (reacting with the same rather than the other finger) for the model in all settings. For experiments with real partners as imitators (Experiments 1, 2, and 4), we also analyzed the imitators' data and expected reliable and independent effects of both imitative and spatial compatibility.

Experiment 1

In Experiment 1, we aimed to replicate the effects of anticipated imitation (Müller, 2016; Pfister et al., 2013, 2017) with finger lifting actions. To that end, participants worked together in pairs. They sat opposite of each other and one participant was assigned the role of "leader" (i.e., model), the other as "follower" (i.e., imitator). Participants' roles were instructed as "leader" and "follower" in keeping with previous methods (Pfister et al., 2013). Participants switched roles after half of the experiment. The model had to respond to imperative color stimuli by lifting either the index or middle finger of the right hand. The imitator always used the left hand and had to either imitate the model's actions or counterimitate the actions in different blocks. Imitative and spatial compatibility were intentionally confounded in this experiment. We thus expected an A-E compatibility influence, that is, faster model actions for imitation compared to counterimitation blocks. Furthermore, we also expected faster imitator actions for imitation compared to counterimitation blocks.

Method

Participants. We recruited 24 participants (M_{age} = 27.92 years, SD = 8.12; 18 females, 23 right-handed). This sample size ensured a power of $1 - \beta = .99$ for the effect size of anticipated imitation reported by Pfister et al. (2013), and it is able to detect medium effect sizes of $d_z \geq 0.6$ with a power of $1 - \beta = .80$. Participants gave informed consent prior to the experiment and received course credit or monetary compensation for participation.

Stimuli and apparatus. Participants were seated face to face at a table and operated two response keys each (see Figure 1A). They could see the upper body of each other as well as the hand operating the response keys. The keys measured 2 cm × 2 cm and were connected to the PC via a Serial Response Box (Psychology Software Tools, Pittsburgh, PA). The two keys of each participant were mounted directly adjacent to each other at a distance of 2 cm from the pair of keys of the other participant. The model was instructed to operate his or her pair of keys with the right hand whereas the imitator was asked to use his or her left hand (see Figure 1B). A 17-in. monitor was placed midway on the table so that only the model was able to observe the screen (to his or her right), while the imitator could not see the screen. The imitator was orally informed about the current task (imitating or counterimitating the model) by the experimenter. Target stimuli were green and red color patches that filled the entire screen to be easily visible even when attending mainly to the imitator's actions. The same setup was used in Experiments 2, 4, and 5.

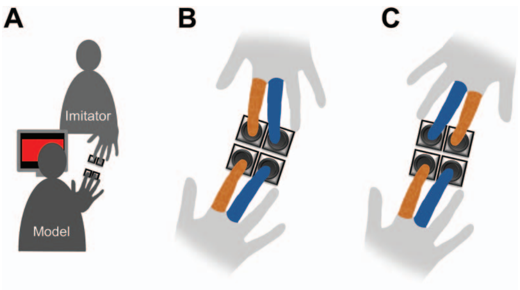

Figure 1. Design of the experiments. (A) In Experiments 1, 2, 4, and 5, two participants sat opposite of each other. The model faced the computer screen, placed to his or her right in Experiments 1, 2, and 5 and to the left in Experiment 4. The model responded to color stimuli by lifting the index or middle finger and the imitator followed by imitating or counterimitating the model's response in different blocks. The model always used the right hand. (B) In Experiment 1, the imitator used the left hand. Thus, imitative and spatial compatibility were confounded. (C) In Experiment 2, the imitator used the right hand, pitting imitative and spatial compatibility against each other. In Experiments 3, 4, and 5, the imitator used left and right hands in different blocks, manipulating spatial and imitative compatibility orthogonally. Note that in Experiment 3 and in one group of Experiment 5, models were imitated by an animated hand presented on a computer screen. See the online article for the color version of this figure.

Procedure. Participants were instructed that they would work jointly on a task in which one participant would be the model and the other participant would be the imitator in a simple action sequence. Model and imitator knew each other's task and switched their role after half of the experiment. Each trial started with "Go!" ("Los!") on the screen, informing the model that the trial was about to start. The model was supposed to read out the word to the imitator and both participants had to press their keys down from this moment onward. After 1,000 ms, the screen turned either red or green, and the model was instructed to lift the index finger in response to one color and to lift the middle finger in response to the other color; color-response mapping was counterbalanced across participant pairs. There was no response deadline though the model was instructed to respond as fast and accurately as possible. The model action blanked the screen and prompted the imitator to respond. In different blocks of the experiment, the imitator was instructed to lift either the same or the other finger as the model. Correct imitator responses terminated the trial and the next trial started after an intertrial interval of 1,000 ms.

Errors during the model action (i.e., the model releasing the incorrect key or the imitator responding prematurely) or the imitator response (i.e., the imitator releasing the incorrect key or the model performing a second response) terminated the trial immediately. Participants received informative error feedback on screen for 1,000 ms, accompanied by a buzzer sound that was played via loudspeakers.

Participants performed 20 blocks of 24 trials each (12 responses with the index finger and 12 responses with the middle finger), and they switched their roles after the first 10 blocks so that each participant acted as model for half the experiment and as imitator for the other half of the experiment. For each experimental half, five consecutive blocks featured compatible imitator responses and five consecutive blocks featured incompatible imitator responses, with compatibility order being counterbalanced across participant pairs.

Results

Data treatment. The data and syntaxes for statistical analyses of all experiments are publicly available on the Open Science Framework (https://osf.io/vznrb/). On a small subset of trials, the response keys produced a noise signal, leading to a premature trial abortion. Those trials were excluded from all analyses (2.9%). Model and imitator response times (RTs) were analyzed separately, but for both RT analyses, all trials with errors of either participant (model or imitator; 5.8%) and all trials following those trials were excluded, as well as the first trial of each block. Furthermore, trials were excluded if the RT was more than 2.5 *SD* from the cell mean, calculated separately for each participant, action role and compatibility (2.6% of model trials, 2.0% of imitator trials). For error rate analysis of the model's data, all trials with correct answers or commission errors of the model during model action were included, but not trials where the imitator had responded prematurely. For error rate analysis of the imitator's data, only those trials with correct answers or commission errors of the imitator were used where the model had responded correctly. Two-tailed, paired *t* tests were calculated to compare RTs and error rate in imitation blocks with those in counterimitation blocks. The main RT results are depicted in Figure 2A.

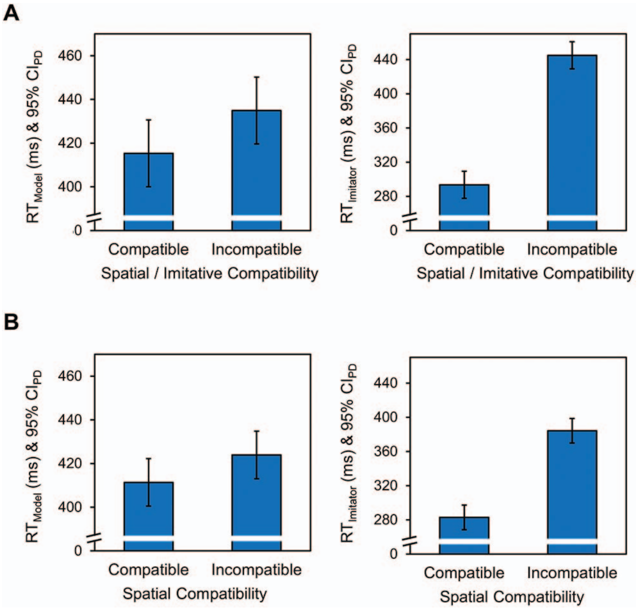

Figure 2. Mean response time (RT) in (A) Experiment 1 and (B) Experiment 2 for model (left panels) and imitator reactions (right panels). In Experiment 1, spatial and imitative compatibility were confounded, whereas in Experiment 2, spatially compatible responses were anatomically incompatible and vice versa. Error bars represent the 95% confidence interval of paired differences (CIPD; Pfister & Janczyk, 2013). Note the difference in *y*-axis scaling between model and imitator panels. See the online article for the color version of this figure.

Model responses. The model reacted faster in imitation blocks (M = 415 ms, SE = 14.66) compared to counterimitation blocks (M = 435 ms, SE = 18.02), $t(23) = 2.66$, $p = .014$, $d_z = 0.54$. Error rates did not differ between imitation and counterimitation blocks, $t(23) = 1.88$, $p = .072$, $d_z = 0.38$, although descriptively more errors were committed in imitation blocks (M = 2.15%, SE = 0.37) compared to counterimitation blocks (M = 1.61%, SE = 0.36). Error rates were overall low in all conditions. Therefore, we additionally analyzed errors rates using generalized linear mixed-effect models (LMMs). The models were fitted using the glmer function from the lme4 package, Version 1.1.12, of the R software environment, Version 3.5.0. Random intercepts were included for participants and we compared a null model with a model that included compatibility. Compatibility did not contribute significantly to model fit, $\chi^2(1) = 2.05$, $p = .152$. Because error rates were descriptively higher in imitation blocks compared to counterimitation blocks, we tested whether the effect of compatibility in the RTs was due to a speed–accuracy trade-off. To that end, we analyzed inverse efficiency scores, calculated as IES = RT/(1 − [percentage of errors/100]) (Townsend and Ashby, 1983). The analysis confirmed the RT results by showing that it was easier for participants to react when being imitated rather than counterimitated (lower inverse efficiency scores for imitation compared to counterimitation), $t(23) = 2.32$, $p = .029$, $d_z = 0.47$.

Imitator responses. The imitator reacted faster in imitation blocks (M = 293 ms, SE = 8.75) compared to counterimitation blocks (M = 445 ms, SE = 20.04), $t(23) = 9.57$, $p < .001$, $d_z = 1.95$. Furthermore, the imitator committed fewer errors in imitation blocks (M = 2.36%, SE = 0.38) compared to counterimitation blocks (M = 5.35%, SE = 0.58), $t(23) = 5.84$, $p < .001$, d_z = 1.19. This was also confirmed in the LMM analysis, showing that compatibility contributed significantly to model fit, $\chi^2(1) = 33.31$, $p < .001$.

Discussion

In Experiment 1, participants work together in pairs. While the model reacted to imperative stimuli by lifting the index or middle finger of the right hand, the imitator reacted in different blocks with the same or the other finger of the left hand. Models reacted faster when they were being imitated rather than counterimitated, replicating previous findings (e.g., Müller, 2016; Pfister et al., 2013, 2017).

The imitator also reacted faster and committed fewer errors when imitating the model rather than responding with the opposite action. These results are in line with previous studies on automatic imitation, although the effect of compatibility in the present experiment (152 ms) was larger compared to most of these studies (e.g., Aicken, Wilson, Williams, & Mon-Williams, 2007; Bertenthal et al., 2006; Brass et al., 2000; Catmur & Heyes, 2011). This pronounced effect of compatibility on the imitator's responses might be due to the specific instructions given to the imitators. While previous studies have primarily used independent target stimuli which coincided with a compatible or incompatible model movements to trigger the imitators' responses (e.g., Aicken et al., 2007; Bertenthal et al., 2006; Brass et al., 2000; Catmur & Heyes, 2011; Otte, Habel, Schulte-Rüther, Konrad, & Koch, 2011; Stürmer et al., 2000; see also Cracco et al., 2018), in the present experiment the model's responses were used to trigger the imitators' responses, that is, imitators had to move the same or the opposite finger as the model. Similar instructions were given to the imitators in the study of Boyer et al. (2012). A comparison of the corresponding conditions from this study reveals a similar large effect of compatibility of 150 ms (d_z = 1.92 as recalculated from the reported F statistic).

The compatibility effect for the model was clearly smaller compared to the compatibility effect for the imitator, also mirroring previous findings (Pfister et al., 2013). This difference likely results from the crucial difference between both roles: The model acts in anticipation of the imitator's response so that the model's compatibility effect relates to anticipated behavior of the social partner, whereas the imitator observes the model's movement so that the imitator's compatibility effect relates to the observed behavior of the social partner.

In the present experiment, spatial and imitative features were confounded. Because the imitator used the left hand and the model the right hand, a spatially compatible reaction (same side) was at the same time anatomically compatible (same finger). To deconfound spatial and anatomical features model and imitator need to use the same hand, and this was tested in Experiment 2. When sitting opposite each other, a spatially compatible reaction (same side) is then anatomically incompatible (other finger; see Figure 1C). Thus, influences of spatial and imitative compatibility are pitted directly against each other.

Experiment 2

In Experiment 2, the same setup as in Experiment 1 was used, but the imitator used the left hand. As the instructions given to the participants might influence how much emphasis participants put on spatial or anatomical features, half of the imitators were instructed in terms of spatial features and the other half in terms of anatomical features. That means, half of the imitators were instructed to react on the same side or the other side as the model, while the other half was instructed to react with the same finger or the other finger as the model.

If spatial and imitative compatibility had contributed equally to the compatibility effect observed in Experiment 1 they should cancel each other out in the setting of Experiment 2. If a robust effect of compatibility were to emerge, however, the direction of this effect would inform about the relative strength of both types of compatibility for anticipated partner responses.

Method

Participants. We collected data of 32 participants (M_{age} = 24.47 years, SD = 5.96, 24 females, 29 right-handed). Sample size was increased to credit the possibility of a reduced effect size due to imitative and spatial compatibility now working against each other. Participants gave informed consent prior to the experiment and received course credit or monetary compensation for participation.

Apparatus and procedure. Setup and procedure were identical to Experiment 1 with the only exception that the imitator was now instructed to use his or her right hand to deconfound spatial and anatomical features (see Figure 1C). Half the participants were instructed in terms of anatomical features by using same instruction as in Experiment 1, whereas the other half of the participants was instructed in terms of spatial features. That is, these participants were instructed to respond either with the key on the same side or on the opposite side when performing as imitators.

Results

Data treatment. As in Experiment 1, the response keys produced noise signals in some trials and those trials were excluded from all analyses (2.3%). For model and imitator RT analyses, all trials with errors of either participant (6.6%) were excluded, all trials following those trials, as well as the first trial of each block. Furthermore, trials were excluded if the RT was more than 2.5 SD from the cell mean, calculated separately for each participant, action role and compatibility (2.4% of model trials, 1.7% of imitator trials). For error rate analysis of the model's data, all trials with correct answers or commission errors of the model during model action were included, but not trials where the imitator had responded prematurely. For error rate analysis of the imitator's data, only those trials with correct answers or commission errors of the imitator were included where the model had responded correctly. Two-tailed, paired t tests were calculated to compare RTs and error rates in spatially compatible/imitatively incompatible blocks with those in spatially incompatible/imitatively compatible blocks. To test whether the results were further influenced by the type of instruction, we calculated a 2 × 2 mixed analysis of variance (ANOVA) with the within-subjects factor spatial compatibility (same side vs. other side) and the between-subjects factor instruction (spatial vs. anatomical) as an exploratory follow-up analysis. The main RT results are depicted in Figure 2B.

Model responses. Models reacted faster when the imitator responded on the same side ($M = 411$ ms, $SE = 11.33$) compared to the opposite side ($M = 424$ ms, $SE = 14.02$), $t(31) = 2.35$, $p = .025$, $d_z = 0.42$. The follow-up analysis showed no influence of instruction, as indicated by a nonsignificant main effect of instruction and a nonsignificant interaction term, $F\text{s} < 1$. The analysis of error rates revealed no difference between spatially compatible ($M = 1.75\%$, $SE = 0.33$) and incompatible blocks ($M = 1.71\%$, $SE = 0.28$), $t(31) = 0.12$, $p = .908$, $d_z = 0.02$. This was also confirmed in the LMM analysis, $\chi^2(1) = 0.01$, $p = .925$. The follow-up analysis showed that, in line with the RT results, there was no significant influence of instruction on error rates, all $F\text{s} < 1$.

We further compared the spatial compatibility effect (calculated as $\text{RT}_{\text{spatially incompatible}} - \text{RT}_{\text{spatially compatible}}$) in Experiment 2 with the compatibility effect in Experiment 1, with a two-sided, two-sample t test. The compatibility effects did not differ between Experiments 1 and 2, $t(54) = 0.80$, $p = .428$, $d_s = 0.22$. These results should be interpreted with caution, however, because the experiments were not optimized for a between-subjects comparison and thus had low power to detect potential differences.

Imitator responses. Imitators reacted faster when reacting on the same side as the model ($M = 283$ ms, $SE = 10.04$) compared to the opposite side ($M = 384$ ms, $SE = 12.10$), $t(31) = 14.46$, $p < .001$, $d_z = 2.56$. The follow-up analysis showed that there was no influence of instruction, as indicated by a nonsignificant main effect and interaction, $F\text{s} < 1$. The analysis of error rates revealed that imitators committed fewer errors when reacting on the same side ($M = 2.75\%$, $SE = 0.31$) compared to the opposite side ($M = 7.10\%$, $SE = 0.69$), $t(31) = 7.45$, $p < .001$, $d_z = 1.32$. This was also confirmed in the LMM analysis, showing that compatibility contributed significantly to model fit, $\chi^2(1) = 75.63$, $p < .001$. The follow-up analysis showed that in line with the RTs there was no significant influence of instruction on error rates, $F\text{s} < 1$.

To compare the spatial compatibility effect (calculated as $\text{RT}_{\text{spatially incompatible}} - \text{RT}_{\text{spatially compatible}}$) in Experiment 2 with the compatibility effect in Experiment 1, we calculated a two-sided, two-sample t test. The compatibility effect in Experiment 1 was higher compared to Experiment 2, $t(54) = 3.15$, $p = .003$, $d_z = 0.85$.

Discussion

As in Experiment 1, participants worked in pairs and the imitator had to imitate or counterimitate the model in different blocks. However, in Experiment 2, imitators used the same hand as the model. A spatially compatible response (same side), thus was at the same time imitatively incompatible (other finger). One group of imitators was instructed to react on the same side or the opposite side of the model, while the other group was instructed to react with the same finger or the other finger compared to the model. The model reacted faster when the imitator followed with a reaction on the same side rather than the other side, indicating that spatial compatibility was more important than imitative compatibility. Furthermore, this effect of spatial compatibility was not significantly different from the effect in Experiment 1, even though in Experiment 1, imitative and spatial compatibility were confounded. These results suggest that for the anticipation of others' actions, only spatial features are relevant, while anatomical features seem to be irrelevant. However, the between-subjects analysis comparing Experiment 1 and 2 might not have been sensitive enough to detect a (small) effect of imitative compatibility. Therefore, we decided to manipulate imitative and spatial compatibility orthogonally within subjects in Experiment 3.

The imitator also reacted faster (and committed fewer errors) when responding on the same rather than the other side as the model, suggesting that spatial features are also predominantly relevant in motor priming responses. However, the effect of spatial compatibility was reduced compared to Experiment 1, implying that imitative compatibility influences imitation on top of spatial compatibility (Bertenthal et al., 2006; Boyer et al., 2012; Catmur & Heyes, 2011).

The exploratory analysis of instruction (in terms of spatial or anatomical features) did not reveal a significant influence on the compatibility effect for the model or the imitator. However, with a sample size of 32 participants, the power to detect even medium between-subjects differences was low ($1 - \beta = .28$). Therefore, no conclusion should be drawn from this finding. Furthermore, it is possible that participants reformulated the instructions for themselves. An instruction to "react with the opposite finger" can be reformulated to "react on the same side" and vice versa, leading to essentially the same instructions in both groups.

Experiment 3

In Experiment 3, we varied imitative and spatial compatibility orthogonally in different blocks. To that end, participants work together with a virtual avatar, which was displayed on a computer screen. We decided to use a virtual person instead of a real person as imitator, to match all conditions in terms of error rates and RTs of the imitator. In Experiments 1 and 2, for the model, imitation and counterimitation conditions were not only different with respect to the compatibility of the following response, but also with respect to the predictability of the imitator's response in terms of delay (i.e., RT of the imitator) and error rate. Even though previous research has shown that it is predominantly the compatibility of model's and imitator's response that drives the model's actions (Pfister et al., 2017), we still opted for a setting with comparable imitator responses in all conditions to better detect small effects of imitative compatibility on the model's actions (for a successful demonstration of an impact of the imitator's delay, see Lelonkiewicz & Gambi, 2017). Thus, in Experiment 3, participants only had the role of the model, while they saw the hand of a virtual person on the computer screen. We decided to display only the hand of a virtual person and not the whole upper body to make finger movements as visible and salient on the display as possible. Participants lifted their index or middle finger in response to imperative color stimuli. In different blocks, a left hand or a right hand was displayed which either imitated the participant's action (i.e., lifted the same finger) or counterimitated the participant's action (i.e., lifted opposite finger). Before each block, participants were informed whether the hand would react with the same or the opposite finger. We expected an influence of spatial compatibility on the model's responses and an (albeit smaller) influence of imitative compatibility.

Method

Participants. We recruited 32 participants as for Experiment 2 ($M_{\text{age}} = 26.00$ years, $SD = 7.43$, 24 females, 29 right-handed). Participants gave informed consent prior to the experiment and received either course credit or monetary compensation for participation.

Stimuli and apparatus. Participants were seated in front of a 17-in. monitor and operated the keys *n*, *m*, and *j* on a standard German QWERTZ keyboard. A picture of an animated female hand was displayed in the center of the display throughout the experiment (see Figure 3). The hand was displayed in resting state (all fingers on the ground) during the main part of a trial and only after participant's reactions, a video of the hand lifting the index or middle finger was displayed (40 frames of 33-ms duration each). The first and the last frame of the video were identical to the picture in resting state, to create the impression that the hand remained on the computer screen throughout the experiment. Pictures and videos were created with the software Poser 10 (Smith Micro Software Inc., Aliso Viejo, CA). Target stimuli prompting participants' responses were a red or blue rectangle (~1.5 × 1.5 cm), superimposed between the index and middle finger of the displayed hand.

Procedure. Participants were instructed that they would perform simple action sequences (lifting the index or middle finger) which would be followed by a movement of another person seen on the computer screen. Each trial started with a reminder that participants should place their index and middle finger of the right hand on the respective response keys and the trial only continued if both keys were pressed down. The trial started with the display of a white cross. After 500 ms, a red or blue rectangle was displayed for 200 ms, prompting participants to lift either the index or middle finger. Color-response mapping was counterbalanced across participants. There was no response deadline though the participants were instructed to respond as fast and as accurately as possible. If participants responded correctly, the video of the hand lifting the index or middle finger was started 300 ms after the participant's response. After the movement was finished, the hand remained in rest for 1,000 ms, before a new trial started. If participants lifted the wrong finger, they received an error feedback and the trial was aborted. This was also the case if participants released one or both response keys early. These latter cases were not included in the analysis of error rates.

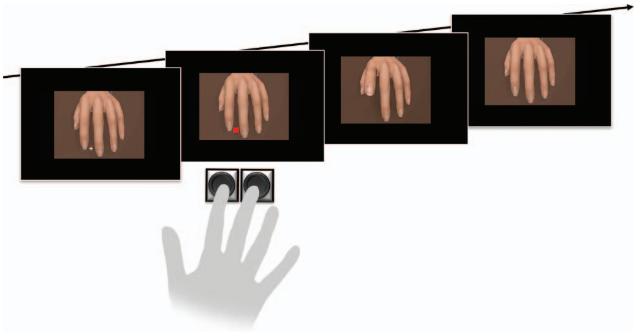

Figure 3. Setting and exemplary trial structure of Experiment 3. The participants sat in front of a computer screen and were imitated by an animated, virtual hand displayed on the screen. In different blocks, left or right hands were displayed to manipulate spatial and imitative compatibility orthogonally. See the online article for the color version of this figure.

To ensure that participants paid attention to the movement of the hand, occasional catch trials were implemented (for a similar procedure see Pfister et al., 2017). In these trials, the delay between participants' reactions and the start of the hand movement was prolonged to 1,000 ms. Participants had to press the *j* key, whenever they detected such a late onset. Each trial had a 1 in 20 chance to be a catch trial (randomly determined at the beginning of each trial), but the first 30 trials of each block were never catch trials. If participants responded correctly to the catch trial, they received a positive message ("Well done!"), whereas they received a warning message to pay more attention to the hand movement, if they missed a catch trial.

In four different blocks, the moving hand on the computer screen was either a left or a right hand, and it could either move the (anatomically) same or different finger compared to the participants' reaction. Before each block, participants were informed whether the hand would react with the same or the opposite finger as the participant (irrespective of the hand identity). The instruction always referred the anatomical features (index or middle finger, same or different fingers), no spatial reference was used. The order of blocks was counterbalanced across participants with the restriction that spatial compatibility was always identical in the first two blocks (i.e., in both blocks the hand either always reacted on the same side or always reacted on the opposite side compared to the participant) and was reversed in the last two blocks. Imitative compatibility, on the other hand, alternated from one block to another. Each block consisted of 120 trials, with an equal number of reactions with the index and middle finger.

Results

Two participants did not detect any of the catch trials. Data from these two participants were excluded from all analyses, because apparently these participants had not paid attention to the hand movements. The remaining participants detected the catch trials with a success rate of 76.68% ($SE = 3.31$). For RT analysis, all trials with errors (4.3%) and all trials following erroneous trials, the first trial of each block, as well as all trials following catch trials were excluded. Furthermore, trials were excluded if the RT was more than 2.5 *SD* from the cell mean, calculated separately for each participant, spatial compatibility and anatomical compatibility (2.1%). For analysis of the error rates, only errors of commission (i.e., lifting of the wrong finger) were included.

To compare RTs and error rates across conditions, a 2 × 2 within-subjects ANOVA with the factors spatial compatibility and imitative compatibility was calculated. The main results are depicted in Figure 4. There was no influence of either spatial or imitative compatibility on RTs and no interaction, all $F\text{s} < 1$. Neither was there an influence of spatial or imitative compatibility on error rates and no interaction, all $F\text{s} < 1$. This was also confirmed in the LMM analysis, $\chi^2(3) = 1.80$, $p = .616$.

Discussion

In Experiment 3, we manipulated spatial and imitative compatibility orthogonally. Participants' reactions were followed by the

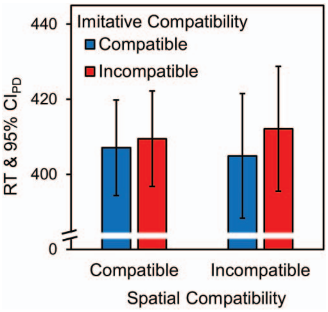

Figure 4. Mean response time (RT) in Experiment 3. Error bars represent the 95% confidence interval of paired differences (CIPD) for the comparison of imitative compatible with imitative incompatible responses, calculated separately for spatially compatible and spatially incompatible responses (Pfister & Janczyk, 2013). See the online article for the color version of this figure.

movement of an animated hand displayed on the computer screen. In different blocks, the movements were spatially compatible or incompatible and anatomically compatible or incompatible. We found no influence of spatial compatibility or imitative compatibility on the participants' responses. These results stand in stark contrast to the first two experiments, in which we found clear evidence for an influence of spatial compatibility on model's RTs.

One difference between Experiment 3 and the first two experiments is that in Experiment 3 performance differences of the imitator between the compatible and the incompatible conditions were eliminated. That is, in Experiment 3, the imitator's (i.e., the avatar's) reactions always followed models' reactions after the same delay, irrespective of the condition (except for the catch trials). In Experiments 1 and 2, in contrast, the imitator responded slower in compatible trials and faster in incompatible trials. This might be taken to suggest that differences in anticipated or perceived delays might have inflated the effects of anticipated imitation (but see Müller, 2016; Pfister et al., 2013). More precisely, previous studies have found that the delay between actions and effects can also be anticipated and can influence action control, so that response are initiated more slowly when a long A-E delay is anticipated compared to a short A-E delay (Dignath & Janczyk, 2017; Dignath, Pfister, Eder, Kiesel, & Kunde, 2014). Therefore, it is possible that compatibility effects in Experiments 1 and 2 were driven by the delay of the imitator's response rather than the identity of the imitator's response (Lelonkiewicz & Gambi, 2017), which would explain the null finding in Experiment 3.

To address such concerns we had investigated whether model's actions are driven by the delay or the identity of the imitator's response in a previous study (Pfister et al., 2017). In the first experiment of this study, the delay of the imitator's response was held constant across compatible and incompatible conditions (long vs. short model actions being imitated or counterimitated by short or long responses of an avatar). Models still reacted faster in the compatible compared to the incompatible condition. In a second experiment, spatial compatibility as well as delay of the imitator's response were manipulated orthogonally. While spatial compatibility influenced model's responses, there was no effect of delay. These results show that the identity of an imitator's response does indeed matter for the impact of anticipated imitation whereas delays in the range of typical experimental setups do not. Thus, the null finding in Experiment 3 cannot be explained by the fact that people generally anticipate the delay, but not the identity of the imitator's reaction.

As an additional test to exclude the possibility that participants anticipated the delay rather than the imitator's reaction we reanalyzed the data of Experiments 1 and 2, in which models were imitated by a human. We included the compatibility effect of the imitator (RT in the incompatible condition minus RT in the compatible condition) as a covariate in the analysis of the model data. The (spatial) compatibility effect of the model remained significant in both experiments, Experiment 1: $F(1, 22) = 6.90, p = .015$; Experiment 2: $F(1, 30) = 5.46, p = .026$, suggesting that the null finding in Experiment 3 cannot be explained by the fact that in the other experiments participants anticipated the delay rather than the identity of the imitator's reaction.[2]

A second difference between Experiment 3 and the other experiments is that participants of Experiments 1 and 2 switched roles midway through the experiment, so that half of the participants acted as imitator before taking the model role. However, this was not the case in Experiment 3, as all participants only completed the model part. To analyze whether carry-over effects can explain the absence of compatibility effects in Experiment 3, we reanalyzed the data of Experiment 1 and 2 and included order of action role (imitator first, model first) as a between-subjects factor. Order of roles did not influence the model compatibility effect—Experiment 1: $F < 1$, Experiment 2: $F(1, 30) = 2.63$, $p = .115$—nor the imitator compatibility effect—Experiment 1: $F(1, 22) = 3.11$, $p = .092$, Experiment 2: $F < 1$. It thus seems unlikely that previous experience as an imitator was a driving force behind the compatibility effects observed in Experiments 1 and 2.

A final difference between the experiments is that the imitator was a real person in Experiments 1 and 2, while we used videos of an animated person as imitator in Experiment 3. This poses the question of whether or not it is possible to find effects of anticipated imitation with such stimuli, because the use of virtual partners likely reduces the degree of humanness participants attribute to the imitator. However, previous studies suggest that also the spatial compatibility of nonsocial action effects influences action control (e.g., Kunde, 2001) and even effects of anticipated imitation in slightly different experimental designs (Pfister et al., 2017). Thus, even if participants treated the avatar's movements as nonsocial stimuli, the results should at least have shown an influence of spatial compatibility.

One possibility why an influence of spatial compatibility was not found in the present experiment is that A-E compatibility influences with nonsocial spatial effects are in fact less robust than previously assumed or even nonexistent (i.e., false-positives). Another, perhaps more likely, possibility is that such spatial A-E compatibility effects are subject to constraints that were not met in the present study. For example, the reduced humanness of the imitator might have such a dramatic effect on spatial A-E compatibility effects (as in Experiment 3) because reducing humanness

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[2] The same analysis was done on the data of the following Experiment 4, in which models were again imitated by another human participant. The influence of (spatial) compatibility on the model's RT remained significant even when the compatibility effect of imitator was included as a covariate, $F(1,62) = 9.46$, $p = .003$, in line with the results of Experiments 1 and 2.

also reduces the relevance of the imitator's movements for the participant's action control. Previous studies have shown that task relevance of social and nonsocial action effects boosts A-E compatibility effects (Ansorge, 2002; Janczyk, Yamaguchi, Proctor, & Pfister, 2015; Müller, 2016; Wirth, Pfister, Brandes, & Kunde, 2016) and one can readily assume that videos on the computer screen are not as relevant for the participants as movements of a real person. We tried to increase the relevance of the avatar's movements by introducing catch trials. This may however have triggered participants to pay more attention to the timing of the imitator's movement rather than the identity. The implementation of catch trials was done in line with a previous study of ours, in which we used the same avatar videos and found an influence of spatial compatibility on model's action (Pfister et al., 2017, Exp. 2). However, in that study only left hand actions of the avatar were used, so that imitative and spatial compatibility were always confounded. This might have boosted the effect of spatial compatibility compared to the present experiment. Still, that study also yielded a smaller effect size as compared to previous experiments with human imitators ($d_z = 0.30$). It thus seems as if the use of animated videos does indeed work against potential effects of anticipated imitation. To further investigate the differential influence of spatial and imitative compatibility on imitation, we therefore decided to repeat Experiment 3, but switch back to a setup with real persons as imitators.

Experiment 4

In Experiment 4, participants worked in pairs as in Experiments 1 and 2. The model reacted to imperative color stimuli and the imitator responded with the same or the opposite finger of the left or right hand in different blocks. Half of the imitators were instructed in terms of spatial features and the other half in terms of anatomical features. We expected an influence of spatial compatibility on the model's responses and the imitator's responses, as well as a possible (albeit smaller) influence of imitative compatibility.

Method

Participants. To be able to detect even small effects of imitative compatibility, we collected data of 64 participants. This ensures a power of $1 - \beta \geq .80$ for effects of $d_z \geq 0.36$. One participant changed their responses from keeping the response keys pressed down throughout the trials and releasing the appropriate response key to pressing and immediately releasing the response key midway through the experiment. Another participant reported that as imitator they had attended to the mirror image of the color as reflected in the other's eyes instead of the other's finger movements. Data of these participants and their partners (two pairs, four participants) was replaced. The final sample of participants was on average 25.02 years old ($SD = 8.55$, 44 females, 62 right-handed). All participants gave informed consent prior to the experiment and received either course credit or monetary compensation for participation.

Apparatus and procedure. The experiment was a close replication of the setup of Experiments 1 and 2 with the only differences that the imitator used the left hand in some blocks and the right hand in the remaining blocks (see Figure 1). The experiment comprised 40 blocks, and participants again switched roles midway through the experiment. Block length was reduced to 20 trials to keep the experiment feasible. For each experimental half, the current imitator used one hand in the first 10 blocks and the other hand in the second 10 blocks, with hand order being counterbalanced across participant pairs. All remaining details were as for Experiments 1 and 2, expect for the screen position which was placed on the left side of the model instead of the right side. As in Experiments 1 and 2, only the model was able to see the screen. Half of the participants were instructed in terms of anatomical features, whereas the other half of the participants was instructed in terms of spatial features.

Results

Data treatment. The response keys rarely produced noise signals as in Experiments 1 and 2 ($<0.1\%$); these trials were excluded from all analyses. For model and imitator RT analyses, all trials with errors of either participant (6.8%), all trials following those trials, as well as the first trial of each block were excluded. Furthermore, trials were excluded if the RT was more than 2.5 *SD* from the cell mean, calculated separately for each participant, action role and compatibility (2.4% of model trials, 1.8% of imitator trials). For error rate analysis of the model's data, all trials with correct answers or commission errors of the model during model action were included, but not trials where the imitator had responded prematurely. For error rate analysis of the imitator's data, only those trials with correct answers or commission errors of the imitator were included where the model had responded correctly. Separate 2×2 within-subjects ANOVAs with the factors spatial compatibility (same side vs. different side) and imitative compatibility (same finger vs. different finger) were calculated to analyze RTs and error rates for the model and the imitator. The main RT results are depicted in Figure 5.

Model responses. A main effect of spatial compatibility showed that models reacted faster when the imitator reacted on the same side (same finger: $M = 431$ ms, $SE = 7.42$; different finger: $M = 437$ ms, $SE = 9.00$) compared to the opposite side (same finger: $M = 443$ ms, $SE = 9.03$; different finger: $M = 442$ ms,

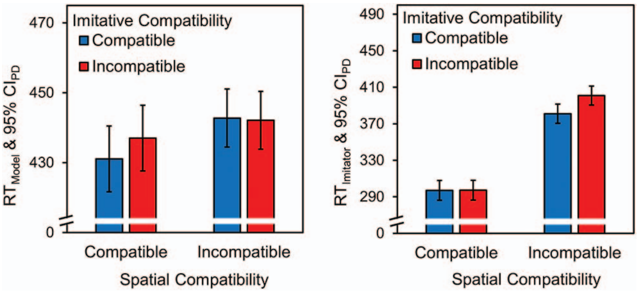

Figure 5. Mean response time (RT) in Experiment 4. The left panel shows the model's RTs, the right panel shows the imitator's RTs. Error bars represent the 95% confidence interval of paired differences (CIPD) for the comparison of imitative compatible with imitative incompatible responses, calculated separately for spatially compatible and spatially incompatible responses (Pfister & Janczyk, 2013). Note the difference in *y*-axis scaling between plots. See the online article for the color version of this figure.

SE = 3.32), $F(1, 63) = 9.29$, $p = .003$, $\eta_p^2 = .13$. There was no influence of imitative compatibility, as indicated by a nonsignificant main effect and interaction, *F*s < 1. To analyze whether the data provided support for the null hypothesis (no influence of anatomical compatibility), we calculated Bayes factors (BFs) using JASP (JASP Team, 2016; Version 0.8.0.1). The analysis revealed $BF_{01} = 5.061$ for when testing additive effects of spatial and imitative against a model of spatial compatibility alone, and $BF_{01} = 15.554$ when testing the saturated model including the interaction of spatial and anatomical compatibility against a simple main effect of spatial compatibility. These results support the null hypothesis of no influence of imitative compatibility.

As follow-up analysis, we calculated a 2 × 2 × 2 mixed ANOVA with the additional between-subjects factor instruction (in terms of spatial vs. anatomical features), to test whether this result pattern was influenced by the type of instruction. The ANOVA revealed no conclusive evidence for an influence of instruction, as indicated by a nonsignificant main effect and interactions, *F*s < 2.10, *p*s > .152. To further investigate whether the data provided support for the null hypothesis (no influence of instruction), we additionally calculated BFs. This analysis revealed that the factor instruction did not influence RTs on top of spatial compatibility but suggested only anecdotal evidence for the null hypothesis in this exploratory analysis ($BFs_{01} > 1.470$). As for Experiments 1 and 2, no influence of action role order on compatibility effects of the model were found, *F*s < 2.62, *p*s > .111.

In the analysis of error rates, no effect approached significance, all *F*s < 1. This was also confirmed in the LMM analysis, $\chi^2(3) = 0.65$, $p = .885$. The follow-up analysis showed that in line with the RTs there was no significant influence of instruction on error rates, all *F*s < 2.92, *p*s > .092.

Imitator responses. A significant main effect of spatial compatibility showed that imitators were faster when reacting on the same rather than the opposite side as the model, $F(1, 63) = 267.54$, $p < .001$, $\eta_p^2 = .81$. Furthermore, a main effect of imitative compatibility revealed that imitators were faster when reacting with the same finger as the model rather than the opposite finger, $F(1, 63) = 8.99$, $p = .004$, $\eta_p^2 = .13$. However, this was modulated by an interaction of spatial and imitative compatibility, $F(1, 63) = 5.52$, $p = .022$, $\eta_p^2 = .08$. Two-tailed, paired *t* tests showed that imitative compatibility only influenced RTs when the imitator reacted on the other side than the model (same finger: *M* = 381 ms, *SE* = 9.85; different finger: *M* = 401 ms, *SE* = 9.51), $t(63) = 3.79$, $p < .001$, $d_z = 0.47$, but not when the imitator reacted on the same side as the model, (same finger: *M* = 297 ms, *SE* = 6.72; different finger: *M* = 297 ms, *SE* = 7.12), $t(63) = 0.05$, $p = .964$, $d_z = 0.01$.

As follow-up analysis, we calculated a 2 × 2 × 2 mixed ANOVA with the additional between-subjects factor instruction (in terms of spatial vs. anatomical features), to test whether this result pattern was influenced by the type of instruction. The ANOVA only revealed a significant influence of instruction on spatial compatibility, $F(1, 62) = 7.32$, $p = .009$, $\eta_p^2 = .11$, indicating a more pronounced effect of spatial compatibility when instructions relied on spatial features rather than anatomical features. There was no main effect of instruction, no interaction of instruction with imitative compatibility and no three-way interaction, *F*s < 1.35, *p*s > .251. As for Experiments 1 and 2, action role order had no influence on compatibility effects of the imitator, *F*s < 2.13, *p*s > .149.

In the analysis of error rates, a main effect of compatibility showed that imitators committed fewer errors when reacting on the same side (same finger: *M* = 3.31%, *SE* = 0.36; different finger: *M* = 3.65%, *SE* = 0.40) compared to the opposite side (same finger: *M* = 5.83%, *SE* = 0.52; different finger: *M* = 5.71%, *SE* = 0.44), $F(1, 86) = 38.50$, $p < .001$, $\eta_p^2 = 38$. No other effect approached significance, *F*s < 1. The LMM analysis showed that spatial compatibility contributed significantly to the model fit, $\chi^2(1) = 76.52$, $p < .001$, while inclusion of the other factors did not further improve the model fit, $\chi^2(2) = 1.24$, $p = .537$. The follow-up analysis showed that there was no influence of instruction on the error rates, *F*s < 1.67, *p*s > .200.

Discussion

In Experiment 4, we manipulated spatial and imitative compatibility orthogonally. Participants worked in pairs and in different blocks, the imitator responses were spatially compatible or incompatible and anatomically compatible or incompatible. For the models' actions, we found a clear influence of spatial compatibility with faster reactions when the imitator followed with a reaction on the same side rather than the other side, in line with Experiments 1 and 2. However, there was no influence of imitative compatibility, indicating that while models anticipated where the imitator would react, they did not represent which finger the imitator would use.

The type of instruction (referring to spatial or anatomical features) did not influence models' reactions, in line with Experiment 2. However, even though the sample size was higher compared to Experiment 2, the power to detect between-subjects differences in the present study was still rather low (1 – β = .5 assuming a medium effect size; note that this factor was mainly introduced for counterbalancing). Potential influences of instruction might therefore be evident when sample size is increased.

For the imitator's actions, we found an influence of both spatial and imitative compatibility, in line with Experiment 2. Imitators were faster (and committed fewer errors) when they reacted on the same side as the model rather than the opposite side. Imitators were also faster when they reacted with the same finger as the model rather than the other finger. This was however influenced by spatial compatibility, and imitators only benefitted from reacting with the same rather than the opposite finger, when they reacted on the opposite side as the model. This result seems to be at odds with a previous study, which suggested that spatial and imitative compatibility exert their influence independently of one another (Catmur & Heyes, 2011). However, several differences in comparison to previous setups may be responsible for this finding. In the present experiments, the imitator responded with different hands across the four conditions (the left hand for "same side, same finger" and for "different side, different finger," the right hand in the remaining two conditions), whereas participants responded with the right hand throughout in previous work. Furthermore, the present task instruction for the imitators directly referred to the models' behavior (i.e., "respond with the same/different key as the model" or "respond with the same/different finger as the model"), while previous studies have used independent target stimuli which coincided with a compatible or incompatible model movement. This could have influenced automatic imitation, as there is evidence that the task context in which an imitator is placed can strongly influence automatic imitation (Ocampo & Kritikos, 2010; van Schie, van Waterschoot, & Bekkering, 2008). This was also evident in the follow-up analysis including the type of instruction (in terms of spatial or anatomical features), which revealed a significant influence of instruction on spatial compatibility. Lastly, the interaction of spatial and imitative compatibility was not predicted beforehand and the significant interaction may therefore reflect a Type I error (Cramer et al., 2016). Thus, the significant interaction of spatial and imitative compatibility in the present experiment should be taken with caution.

Experiment 5

While pronounced effects of spatial compatibility on models' actions emerged for all present experiments with a human imitator (Experiments 1, 2, and 4), this was not the case with an animated avatar hand (Experiment 3). Three accounts might explain this unexpected difference in results. First, the lack of compatibility effects might be due to the reduced humanness of the avatar which rendered participants less likely to anticipate the ensuing action effects. Second, seemingly small variations in the design relative to the remaining experiments could have eliminated the A-E compatibility effect for technical reasons. Third, the null findings of Experiment 3 might reflect a possible Type II error. To decide between these three alternatives, we ran a control experiment in which we directly compared the avatar setting to a setting with a human partner. We thus invited two groups of participants, one group interacted with the computer avatar (as in Experiment 3) while the other group interacted with a human partner (as in Experiments 1, 2, and 4). In both groups, anatomical and spatial compatibility were manipulated orthogonally. That is, while models always used the right hand, the imitator (i.e., another participant or the computer avatar) used the left or the right hand and responded either with the same or the opposite finger in different blocks. We expected an influence of spatial compatibility on model's actions in the group imitated by a human partner (as in Experiment 4), whereas this effect should be reduced or absent in the group imitated by the avatar (following Experiment 3). We used an increased sample size relative to Experiment 3 to address the possibility of a Type II error and paralleled minute details of the experimental setup between groups (see the Method for details).

Method

Subjects. We recruited 96 participants. This ensured a power of $1 - \beta \geq .80$ to detect an effect size of $d_s \geq 0.6$ for the between-groups comparison and it further ensured a similar power for a within-subjects effect of $d_z \geq 0.4$ in each group.

Data collection was done in two steps: We first collected data of 32 participants in the avatar group. We then tested the data of these participants for an influence of spatial compatibility. A significant influence of spatial compatibility would have indicated a Type II error in Experiment 3 and we therefore planned to stop data collection in this case. However, because no influence of spatial compatibility was found, we continued data collection until the planned sample size of 48 per group was reached to compare compatibility effects between the two groups (see also the preregistration at https://osf.io/g3u9f/).

Apparatus and procedure.

Avatar imitator. The setup for the group of participants who interacted with the computer avatar was similar to Experiment 3. Slight adjustments were made to the apparatus, the trial procedure, and the animation of the hand movement to increase resemblance with the experiments with a human imitation partner. To that end, external response keys were used which were fixed directly below the computer screen. Thus, index and middle finger of the participants were positioned directly adjacent to the fingers of the computer avatar in the video, mimicking the setup used with human participants. Furthermore, the video of the hand lifting actions was sped up to resemble finger lifting actions of the participants more closely (26 frames of 10 ms duration each, displayed with a 100 Hz monitor). At the beginning of each trial, participants had to press down and hold the two external keys in front of the display with their index and middle finger. Then, the blue or red target stimulus appeared. The target stimulus was displayed until the onset of the avatar's movement (i.e., until 300 ms after the participant's reaction). To prompt participants to pay close attention to the avatar's movements, we instructed them to monitor the avatar's actions and lower their lifted finger together with the avatar. Participants received an error message if they lowered their finger early (i.e., pressed the response key before the avatar began to lower its finger) or late (i.e., pressed the response key later than 200 ms after the avatar finished its movement). Catch trials, that is, delayed responses of the avatar as in Experiment 3, were not included.

Human imitator. The setup for the group of participants who interacted with a human partner was a close replication of Experiment 4. Changes were only made with respect to the target stimuli (the display changed to either blue or red instead of green or red, prompting participants' finger lifting actions) and the screen position, which was placed on the right side of the model instead of the left side as in Experiments 1 and 2. Additionally, models were instructed to monitor the imitators' actions and to lower their lifted finger together with the imitators. No error messages were displayed when models lowered their finger too early or too late but participants could verbally correct their partner when observing such timing errors. All participants were instructed in terms of anatomical features.

Results

Data treatment. Only the model's data was analyzed because in the avatar group participants only completed the model's part. In the avatar group, one participant was excluded from the analyses, because of an extraordinarily high error rate in one condition (>30%) that seemed to be due to the fact that the participant struggled to align the finger movements with the avatar's movements.

For RT analyses, all trials with errors were excluded (7.2% in the avatar group, 1.6% in the human interaction group), all trials following erroneous trials, and the first trial of each block. In the human interaction group, trials were excluded if either participant responded erroneously. Furthermore, trials were excluded if the model's RT was more than 2.5 *SD* from the cell mean, calculated separately for each participant and compatibility (2.5% in the avatar group, 2.6% in the human interaction group). For error rate analysis of the model's data, all trials with correct answers or commission errors of the model during model action were included. In the human interaction group, trials where the imitator had responded prematurely were excluded. To compare RTs and error rates across conditions depending on the type of interaction partner (avatar vs. human), a 2 × 2 × 2 mixed ANOVA with the within-subject factors spatial compatibility and imitative compatibility and the between-subjects factor interaction partner was computed.

RT and error rate analysis. The main RT results are depicted in Figure 6. The ANOVA revealed a significant interaction of spatial compatibility and interaction partner on RTs, $F(1, 93) = 5.85$, $p = .018$, $\eta_p^2 = .06$. No other effect was significant, all Fs < 1. To follow up on this analysis, two separate 2 × 2 within-subjects ANOVAs with the factors spatial compatibility and imitative compatibility were calculated for each group. In the avatar group, the ANOVA revealed no influence of either spatial, $F(1, 46) = 1.76$, $p = .191$, $\eta_p^2 = .04$, or imitative compatibility on RTs, $F < 1$ (same side, same finger: $M = 449$ ms, $SE = 12.21$; same side, different finger: $M = 443$ ms, $SE = 12.72$; opposite side, same finger: $M = 435$ ms, $SE = 10.22$; opposite side, different finger: $M = 442$ ms, $SE = 12.14$). The interaction of spatial and imitative compatibility was also not significant, $F(1, 46) = 1.95$, $p = .169$, $\eta_p^2 = .04$. In the human interaction group, a main effect of spatial compatibility showed faster model actions when the imitator reacted on the same side (same finger: $M = 439$ ms, $SE = 12.39$; different finger: $M = 437$ ms, $SE = 13.25$) compared to the opposite side (same finger: $M = 447$ ms, $SE = 14.52$; different finger: $M = 446$ ms, $SE = 13.29$), $F(1, 47) = 6.07$, $p = .017$, $\eta_p^2 = .11$. There was no influence of imitative compatibility, as indicated by a nonsignificant main effect and interaction, Fs < 1.

The analysis of error rates revealed that participants interacting with the avatar committed more errors than participants interacting with another human, $F(1, 93) = 83.41$, $p < .001$, $\eta_p^2 = .47$. No other effect was significant, all Fs < 1.

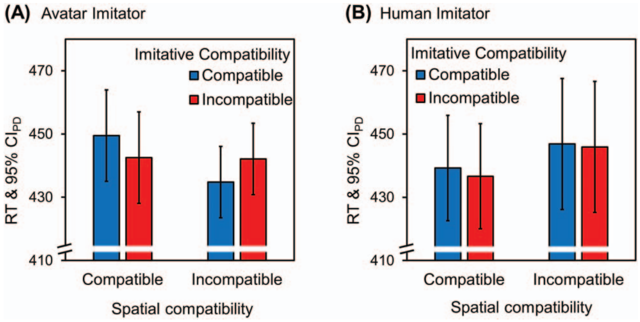

Figure 6. Mean response time (RT) in Experiment 5. (A) Model RT in the group of participants who interacted with the virtual avatar. (B) Model RT of participants who interacted with a human partner. Error bars represent the 95% confidence interval of paired differences (CIPD) for the comparison of imitatively compatible with imitatively incompatible responses, calculated separately for spatially compatible and spatially incompatible responses. See the online article for the color version of this figure.

Discussion

In Experiment 5, one group of participants interacted with a computer avatar (i.e., an animated avatar hand as in Experiment 3) while the other group interacted with a human partner (as in Experiment 4). In both groups, spatial and imitative compatibility were manipulated orthogonally. We found a significant influence of interaction partner (avatar or human) on spatial compatibility effects. That is, a clear influence of spatial compatibility only emerged when participants were imitated by another person. Participants reacted faster when the imitator followed with a reaction on the same side rather than the other side, replicating the results of Experiment 4. In contrast, we found no influence of spatial compatibility on models' action when they were imitated by the avatar, replicating the results of Experiment 3. Imitative compatibility did not influence models' actions in either setting.

Taken together, these results corroborate the assumption that the null finding in Experiment 3 is indeed due to the fact that participants interacted with a computer avatar rather than a real human and that the reduced humanness of the avatar rendered them less likely to anticipate the ensuing action effects. In addition, the results suggest that if a partner's reaction was anticipated (i.e., when participants were imitated by another human), models anticipated where the imitator would react, but they did not represent which finger the imitator would use.

General Discussion

The present experiments were conducted to investigate how sociomotor actions are represented, that is, how social action effects are used for effect-based action control. To that end, we used an experimental setup which could disentangle the contribution of spatial compatibility and imitative compatibility to the influence of anticipated imitation on action control (following work on automatic imitation; Bertenthal et al., 2006; Boyer et al., 2012). Model's actions were clearly influenced by spatial compatibility, but we found no support for the influence of imitative compatibility on the model's performance. In contrast, the imitator's actions were influenced both by spatial and imitative compatibility, suggesting that both anatomical and spatial features can be primed. These results suggest that while anatomical and spatial features can exert an influence, models only anticipated spatial features, while anatomical features were not anticipated and thus could not exert any influence. Thus, it seems that while motor actions can be retrieved by anticipating the behavior they evoke in others, anatomical features of the other's behavior are not automatically included in this process. This seems plausible considering that in interactions with another person (e.g., when tossing a ball to someone), it is generally more important for the planning and execution of an action where and when the other person will react rather than which effector he or she is going to use (even though, in many cases, this can be confounded).

This is not to say that action control necessarily ignores anatomical features, and they might still bias responding when they are sufficiently salient. For instance, in a previous study participants engaged in more nose scratching or hair stroking behavior, when they anticipated that another person would perform the respective action (Genschow & Brass, 2015). Thus, anatomical features of others' actions might be included in action control, when they are relatively salient or when these features are integral to the action at hand.

The present experiments clearly showed that anticipating another real life person's reactions can facilitate own actions, replicating findings of previous studies (Müller, 2016; Pfister et al., 2013). Thus, accumulated evidence suggests that the behavior of another real life person is used for own action control. As in the previous studies, models working together with a human partner in the present experiments (Experiments 1, 2, 4, and 5) did not need to attend to the imitators' actions to complete their own task. Nevertheless, reliable effects of the imitator's behavior were found. This is particularly interesting compared to the experiments, where participants saw a virtual hand on the computer screen imitating their actions (Experiment 3 and one group of participants in Experiment 5). No reliable compatibility effects of the following hand movement were found, when participants were imitated by a virtual hand, even though participants had to attend to the imitating actions as the imperative stimuli were superimposed between index and middle finger of the virtual hand and participants were specifically instructed to attend to the hand movements to detect the catch trials (Experiment 3) or to lower their finger in synchrony with the avatar (Experiment 5). This finding suggests that social action effects are somewhat special in that they seem to be particularly salient compared to many inanimate action effects and cannot be as easily ignored. Similar effects can be expected for virtual stimuli if they are more strongly related with social interactions such as handshakes as compared to the present finger-lifting actions (Flach et al., 2010).

In the present experiments, imitation and counterimitation responses followed contingently after model's responses (except for errors of the imitator). Thus, the outcome of an action was always predictable for the model. Models' actions may however be influenced differently when their social counterpart imitates less contingently. Previous studies on nonsocial action effects suggest that low contingency between actions and effects hinders formation of A-E associations (Elsner & Hommel, 2004). This may be similar for social action effects. However, others' behavior is generally not perfectly contingent. Sometimes, others choose to react differently than expected or the other person commits an error. Thus, for the formation of associations between actions and social action effects, different levels of contingency might be feasible compared to nonsocial action effects; the level of contingency and its influence on model's action might even be partner-specific (Kunde et al., 2018). Exploratory observations do indeed suggest that the level of partner contingency affects model performance (Dignath, Lotze-Hermes, Farmer, & Pfister, 2018). Participants in these studies interacted with different (videotaped) partners who responded with different degrees of contingency. Even though this study mainly aimed at showing an impact of contingency on social affiliation ratings, performance of the nonspeeded model responses was better in conditions with high as compared to low contingency. Furthermore, irregularities of others' behavior per se can also influence our own actions. For instance, observing another person committing an error can slow down our own actions (observation-related posterror slowing; De Bruijn, Mars, Bekkering, & Coles, 2012; Schuch & Tipper, 2007). This seems to be particularly evident when we are directly involved because the other's action is a reaction to our own action (Weller, Schwarz, Kunde, & Pfister, 2018). It remains for future research to establish boundary conditions, when social action effects are integrated particularly well into own action control.

Finally, social action effects also comprise settings in which responses of social partners share only few characteristics with the agent's original response. For instance, an agent might verbally ask or command another person to perform a certain action such as opening the window, handing an object or the like. Such commanded actions of another person can also be viewed from the perspective of sociomotor action control (Kunde et al., 2018) – whether or not the present results extend to such situations with less direct matching between different responses remains to be explored in future work.

To conclude, our experiments show that anticipated responses of social interaction partners are mainly represented in terms of spatial rather than anatomical features. In that regard, social action effects do not differ from inanimate action effects and can be exploited for action control just as well.

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Received February 21, 2018
Revision received March 5, 2019
Accepted March 21, 2019 ■