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AUTOMATIC IMITATION OF PHYSICALLY IMPOSSIBLE MOVEMENTS

Roman Liepelt
Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

Marcel Brass
Ghent University, Ghent, Belgium

Motor priming refers to the direct matching of an observed action onto the observer's motor repertoire (Iacoboni et al., 1999) leading to a tendency to automatically reproduce the action. Recent research has shown diminished automatic imitation when observing nonbiological agents, biomechanically impossible actions, and non-intentionally produced actions. However, the question of whether automatic imitation also occurs for physically impossible actions remains open. We found motor priming effects of the same size for both physically possible and impossible movements in a choice-reaction task paradigm (Experiment 1). Both physically possible and impossible movements also elicited identical motor priming effects when attention was drawn to the difference between possible and impossible movements (Experiment 2). While previous research clearly showed a sensitivity of the automatic imitation system to biological plausibility and attributed intentionality, the present findings show its insensitivity to physical plausibility, a finding that remains unaffected by top-down influences.

From personal experience as well as from systematic experimental research in social psychology we know that humans often tend to end up in a posture similar to that of a social interaction partner (Lakin & Chartrand, 2003). Such phenomena reflect a tendency to reproduce observed actions completely unintentionally and automatically. It is now widely assumed that automatic imitative response tendencies result from a more or less direct mapping of the observed behavior onto the observer's motor repertoire (Iacoboni et al., 1999). To investigate automatic imitation of others' actions under controlled experimental conditions, a range of motor priming paradigms have been devised (see Blakemore & Frith, 2005; Brass & Heyes, 2005). Typically, participants have to execute preinstructed finger move-

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Correspondence concerning this article should be addressed to Roman Liepelt, Max Planck Institute for Human Cognitive and Brain Sciences, Department of Psychology, Stephanstr. 1A, 04103 Leipzig, Germany. E-mail: liepelt@cbs.mpg.de.

ments in response to compatible and incompatible finger movements (Brass, Bekkering, & Prinz, 2001). In a more sensitive version, participants have to respond to a symbolic stimulus (e.g., a digit) that instructs either a movement compatible or incompatible with the observed finger-lifting movement. While this research established the basic finding that observed actions automatically prime a corresponding motor representation in the observer (Bertenthal, Longo, & Kosobud, 2006; Brass, Bekkering, Wohlschläger, & Prinz, 2000), recent research has attempted to investigate the specific conditions under which automatic imitation occurs.

AUTOMATIC IMITATION OF BIOLOGICAL AND NONBIOLOGICAL ACTION

Behavioral studies have found stronger motor priming effects when observing human actions compared to physically similar, nonbiological events. Press, Bird, Flach, and Heyes (2005), for example, found that human models elicit a substantially larger automatic imitation effect compared to robotic models. The human bias was found when participants were required to execute a prespecified response (to open their hand) while observing a human or robotic hand making a compatible (opening) or incompatible (closing) movement. In line with these findings, Kilner, Paulignan, and Blakemore (2003) showed that human movements interfere with movement execution but robotic movements do not. Similar findings with respect to biological motion were demonstrated with a social version of the Simon task. The Simon effect entails better performance when irrelevant stimulus location corresponds with the response location than when it does not. Tsai and Brass (2007) recently showed that the human co-representation system is biologically tuned. In this study, participants performed a Simon task either with an image of a human hand or with a wooden analogue. The Simon-like effect only emerged when participants coacted with a biological agent.

Consistent with the behavioral findings, neuroimaging studies have found stronger motor-related activation in so-called mirror areas when observing human action compared to robotic action (Tai, Scherfler, Brooks, Sawamoto, & Castiello 2004). Furthermore, Buccino and colleagues showed that actions that are already represented in the observer's action repertoire produce a stronger activation in mirror areas (Buccino et al., 2004). Perani et al. (2001) found differential activations in brain areas engaged in perceptual and visuomotor processing when comparing real actions in their natural environment with actions produced by a virtual-reality hand. Interestingly, Costantini et al. (2005) found a similar dissociation for the observation of possible and biomechanically impossible finger movements. While premotor areas code human actions regardless of whether they are biologically possible or impossible, sensorimotor parietal regions seem to be sensitive to biomechanical plausibility of actions.

TOP-DOWN MODULATION OF BIOPHYSICALLY IMPOSSIBLE ACTIONS

Another line of research that tried to determine the conditions under which automatic imitation occurs manipulated higher-level action goals and the intentionality of the observed movement. This research is based on the recent assumption that also higher-level representations such as action goals and action intentions are shared (Bekkering & Prinz, 2002; Bekkering, Wohlschläger, & Gattis, 2000; Gattis, Bekkering, & Wohlschläger, 2002; Gergeley, Bekkering, & Király, 2002; Liepelt, von Cramon, & Brass, 2008; Longo, Kosobud, & Bertenthal, 2008; Meltzoff, 1995; Stanley, Gowen, & Miall, 2007).

Longo et al. (2008), for example, showed similar motor priming effects for biologically possible and impossible movements. When attention was drawn to differences between possible and impossible movements, however, only possible movements elicited motor priming effects. Stanley et al. (2007) showed that the observer's belief regarding the origin of a moving dot (human vs. computer-generated) modulates the processing of the dot movement stimuli on their later integration within the motor system. The belief regarding their biological origin was a more important determinant for the interference effects than the stimulus kinematics. Following this line of investigation, Liepelt and colleagues found differential motor priming effects for identical movements depending on whether participants believed that the observed movement was intentionally produced or not (Liepelt et al., 2008). Taken together, all these studies seem to strongly imply that automatic imitation effects are modulated by top-down influences. They are sensitive to (a) the biological nature of the stimuli, (b) the biophysical plausibility of the movement, and (c) the assumed underlying intentionality. However, it has not yet been investigated whether biologically plausible actions that are physically impossible lead to differential motor priming effects. Answering this question will clarify whether automatic imitation is primarily based on high-level representations of the observed movement or is concerned with basic physical properties. Physically impossible behaviors usually do not occur in people's environments (except in illusionist shows or on television). Therefore, answering the present question can also provide new insights for an evolutionary developmental perspective of the mirror system.

THE PRESENT STUDY

In contrast to previous studies investigating the impact of biological plausibility and attributed intentionality on the automatic imitation system, the present study investigates the sensitivity of the automatic imitation system to physical plausibility. In particular, we investigated whether physically impossible but biomechanically (kinematically) possible movements show attenuated motor priming effects as compared to physically possible actions. Further, this study tested whether directing attention to the physical plausibility of the movement leads to similar top-down modulation effects as previously shown for biological plausibility and intentionality (Liepelt et al., 2008; Longo et al., 2008; Stanley et al. 2007). To our knowledge the physical plausibility of movements has only been investigated in the perceptual domain. Using pairs of alternating photographs of a human body, Shiffrar and Freyd showed that with short stimulus onset asynchronies (SOAs), participants tend to report the shortest movement paths despite violations of anatomical constraints (Shiffrar & Freyd, 1990). With increasing SOAs, observers became increasingly likely to report the anatomically possible, but longer, movement paths. This indicates that given enough time the visual system prefers an appropriate apparent motion path.

We adapted the motor priming paradigm of Brass and colleagues (Brass et al., 2001) to test the effect of physical plausibility on the automatic imitation system. Participants were presented with motion stimuli showing left-hand index finger movements either upwards (lifting movement) or downwards (tapping a surface). In the physically impossible condition, the finger on the screen moved through a barrier. In Experiment 1, participants had to perform a choice reaction (either lifting or tapping) in congruent (imitative) or incongruent (contra-imitative) movement blocks. They saw both physically impossible and physically possible movements. In Experiment 2, we directed attention to the physical plausibility using a choice-reaction task. Participants had to respond with two (either index or middle) fingers only, with lifting movements either in congruent (imitative) or incongruent (contra-imitative) movement blocks. The size of the automatic imitation effect was determined by a comparison of congruent with incongruent responses, with automatic imitation referring in this study to the activation of a corresponding motor response by movement observation. This can either lead to a facilitation effect, an interference effect, or both.

Based on the previous literature that showed a sensitivity of automatic imitation to a number of factors, we predicted smaller motor priming effects for physically impossible actions as compared to physically possible actions.

EXPERIMENT 1

Using a choice-reaction task, we tested whether physically possible and impossible movements produce differential motor priming effects. The hand of the model performed either free finger movements (physically possible) or constraint movements in which the fingers moved in a physically impossible way through Lego bricks (see Figure 1). The hand was presented from a third person's perspective whereby the index finger was either lifted or tapped on the table. The beginning of the observed movement was the imperative signal to participants to start their movement. There were two kinds of blocks in which participants had to respond either in an imitative or nonimitative way so that responses were either congruent or incongruent to the observed action. Participants were given instructions about the block that was to be performed at the beginning of each block. We predicted an attenuation of motor priming effects for physically impossible actions, as compared to physically possible actions.

METHOD

Participants. A group of 20 undergraduate students (11 male, mean age: 23.5) participated in this experiment. All were right-handed, had normal or corrected-to-normal vision, and were naive with regard to the hypotheses of the experiment. Participants were paid €7 for their participation. Participants in both experiments gave written informed consent to participate in the study, which was conducted in accordance with the standards of the ethics committee of the University of Leipzig and with the ethical standards laid down in the 1975 Declaration of Helsinki.

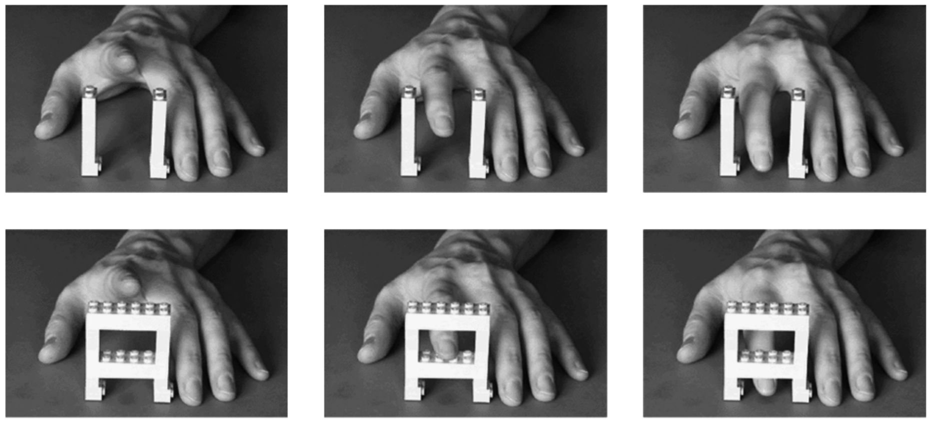

FIGURE 1. Physically possible, non-constrained (upper row) and physically impossible, constrained (lower row) finger-lifting (left), neutral (middle) and finger-tapping (right) movements of Experiment 1.

Apparatus and Stimuli. Stimuli were presented on a 17-inch color monitor that was connected to a Pentium I PC. Experiments were carried out using ERTS software (*Experimental Runtime System*; Beringer, 2000). The sequence of hand movements consisted of three pictures showing a left hand positioned to mirror participants' response hand (see Figure 1). At a viewing distance of 80 cm, the hand on the screen subtended a visual angle of 9.57° x 10.27°.

Two types of movements were presented: The *Physically Possible Condition* (Possible movements) and the *Physically Impossible Condition* (Impossible movements). In the Possible movement condition, the first frame showed the hand with the index finger lifted in a medium position without a constraint (see Figure 1, upper middle). The second frame showed a nearly complete lifting or tapping movement. The third frame consisted of an unconstrained complete lifting (see Figure 1, upper left) or tapping movement (see Figure 1, upper right). In the Impossible movement condition, the observed fingers were physically constrained by a Lego brick (see Figure 1, lower middle), but the fingers moved through the object with a lifting (see Figure 1, lower left) or tapping movement (see Figure 1, lower right) in a way that was physically impossible. The kinematics of the action (lifting or tapping the finger) were the same for Possible and Impossible movements. Both conditions differed with respect to action context only. Reaction times were recorded with the help of a response device which detected the lifting or the tapping movement using mechanical sensors.

Procedure and Design. An adapted version of the paradigm developed by Brass et al. (2001) was used in this experiment. Participants had to either lift or tap the index finger of their right hand. In congruent trials, the observed and the required response finger were both either lifted or tapped in the same way. In incongruent trials, the required response finger tapped while the observed finger was lifted and vice versa. Participants were instructed to respond to the onset of the observed movement as quickly as possible. The stimulus material (observed lifting or tapping movements) for Possible movements and Impossible movements were randomly presented. Participants were given four blocks. Within one block 60 trials were presented and blocks could be either imitative or contra-imitative. Par-

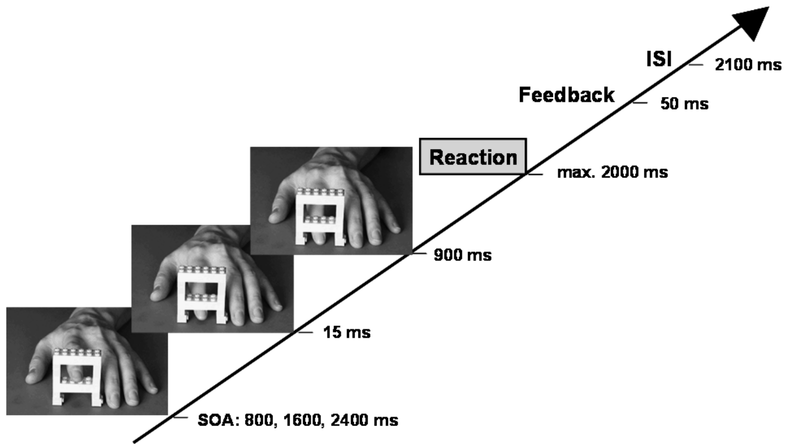

FIGURE 2. Shown is the stimulus sequence for finger-tapping trials, depicting a finger movement as used in Experiment 1. Each trial started with a picture displayed with a variable stimulus onset asynchrony (SOA) of 800, 1600 or 2400 ms, showing a hand with an index finger placed in a middle position. In the second frame (displayed for 15 ms), the finger appeared slightly above the table. In the third frame (displayed for 900 ms), the finger appeared on the table. Participants had to respond within 2000 ms. The reaction was followed by a tonal feedback for 50 ms and a constant inter-stimulus interval (ISI) of 2100 ms.

ticipants had to perform 240 trials in total. Block order was counterbalanced across participants. Each trial started with a picture displayed with a variable SOA of 800, 1600, or 2400 ms showing a hand with the index finger placed in a middle position to ensure that participants attentively processed all stimuli. In the second frame (displayed for 15 ms), the finger appeared slightly above the table. In the third frame (displayed for 900 ms) the finger appeared on the table (tapping movement). Participants had to respond within 2000 ms. The reaction was followed by a tonal feedback for 50 ms that informed participants about the correct use of the response board and a blank screen given at a constant interstimulus interval (ISI) of 2100 ms (see Figure 2).

RESULTS

RT Analysis. Prior to statistical analyses of both experiments, all trials in which responses were incorrect or slower than 2000 ms were excluded from statistical Reaction Time (RT) analyses. This resulted in the elimination of 2.9% of trials from the data set. When needed, a Greenhouse-Geisser correction was used to assess the significance of each effect. RTs and percentage errors for Possible and Impossible movements are presented in Figure 3.

To test effects of *Physical possibility,* we used a 2 x 2-factorial design with the 2-level factor *Physical possibility* (Possible movements, Impossible movements), as well as *Congruency* (congruent, incongruent), both as within-subject variables. We performed the same analyses for error data.

We observed a main effect of *Physical possibility,* $F(1, 19) = 18.05$, $MSe = 263.61$, $p < .001$, partial $\eta^2 = .49$, indicating slower RTs for Impossible movements, as compared to Possible movements. Furthermore, we observed a significant effect of *Congruency*, $F(1, 19) = 172.13$, $MSe = 743.76$, $p < .001$, partial $\eta^2 = .90$. This effect

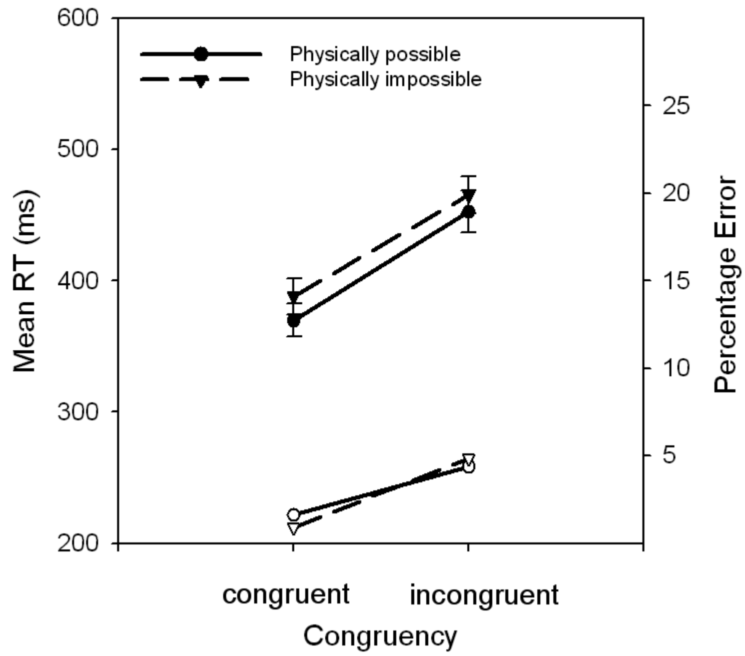

FIGURE 3. Mean reaction times (RTs) in milliseconds (ms) with error bars representing standard errors of the mean (filled symbols) and percentage error (unfilled symbols) for Experiment 1, as a function of observed movement type (physically possible and physically impossible movements) and congruency (congruent and incongruent).

was due to faster RTs in congruent as compared to incongruent trials. We found no significant interaction of *Physical possibility x Congruency, F* < 1, indicating no differences in motor priming for Possible and Impossible movements.

Planned *t*-tests indicated a motor priming effect in the Possible movement condition amounting to 83 ms, $t(19) = 9.87$, $p < .001$. We also observed a significant motor priming effect for Impossible movements, amounting to 77 ms, $t(19) = 14.10$, $p < .001$.

For an overview of RTs and percent errors in congruent and incongruent conditions of Experiment 1, including main effects, see Table 1.

Error Analysis. We found no main effect of Physical possibility, ($F < 1$), but a significant effect of Congruency, $F(1, 19) = 13.67$, *M*Se = 14.42, $p < .05$, partial $\eta^2 = .42$, due to increased error rates in incongruent conditions. Furthermore, we observed no significant interaction of Physical possibility x Congruency, $F(1, 19) = 1.22$, *M*Se = 5.68, $p > .28$, partial $\eta^2 = .06$, indicating no difference in motor priming for errors between both task conditions ruling out a speed-accuracy trade-off (SAT) for observed RT effects.

TABLE 1. Mean reaction times (RTs) in milliseconds (ms) and percent errors (upper part) are shown for physically possible (non-constrained) and physically impossible (constrained) movement conditions of Experiment 1. Corresponding *p*-values for within-subjects effects (lower part) are shown separately for RTs and percent errors.

Condition	RT (ms)	Error (%)
Congruent possible	370	1,6
Congruent impossible	388	0,9
Incongruent possible	453	4,4
Incongruent impossible	465	4,8
Within subjects	**p(RT)**	***p*(Error)**
Congruency (C)	<.000*	.002*
Physical possibility (P)	<.000*	.839
C x P	.463	.284

Note. *sign ($p < .05$)

DISCUSSION

We tested whether physically possible and physically impossible movements produce differential automatic imitation tendencies using a choice-reaction task. In line with previous findings (Brass et al., 2000), we found a significant motor priming effect for physically possible movements. However, in contrast to our predictions we also found a significant motor priming effect for physically impossible movements that was almost identical to the one observed for physically possible movements. These results suggest that physically possible and impossible movements are not differently represented in the automatic imitation system. However, two possible alternative interpretations might drastically limit the validity of the findings of Experiment 1. First, participants might not have perceived the movement as physically impossible. Research investigating apparent motion perception reports that two sequentially presented objects are perceived along the shortest path between them. However, when using photographs of human body postures, it was demonstrated that, given enough time, participants do not perceive a biomechanical impossible short movement path but rather a longer path that is biomechanically more plausible (Chatterjee, Freyd, & Shiffrar, 1996; Shiffrar & Freyd, 1990). This could explain the lack of differential motor priming effects in the present experiment. Participants might have interpreted the finger as not going through the barrier, but as passing behind the brick, making the observed movement physically possible (Chatterjee et al., 1996; Stevens, Fonlupt, Shiffrar, & Decety, 2000). Second, as has been outlined earlier, differences between physically possible and impossible movements might only be detected when directing attention via instructions to the way the movement is performed (Longo et al., 2008; Stanley et al., 2007). Verbal reports from some of our participants indicated that they did not even recognize that the movement was physically impossible. Participants could have shown a form of inattentional blindness to the way the specific movements were performed (Longo et al., 2008; Mack & Rock, 1998).

EXPERIMENT 2

We designed a second experiment which manipulated the physical possibility of the movement directing attention to the way the movement was performed to rule out the possibility that inattentional blindness was the reason for the failure to find a modulation of automatic imitation. Similar to previous studies (Liepelt et al., 2008; Longo et al., 2008; Stanley et al., 2007), participants were told at the beginning of the experiment that they would see two kinds of movements, "normal" and "impossible" finger-lifting movements. We gave participants pre-experimental experience with both variants of the stimulus situation presented on the screen. Participants had to produce the finger-lifting movement between two open Lego bricks (for the physically possible condition) and to try to lift their finger against the closed Lego barrier (for the physically impossible condition). Participants were instructed to raise each finger twice. To rule out alternative interpretations of the observed impossible action condition such as perceiving the finger as moving behind the barrier in a physically possible way, we created new stimulus material. We added metal clamps to the moving fingers which prevented the model from moving the finger around the Lego brick (see Figure 4). These metal clamps were also added to participant's fingers in both conditions during pre-experimental experience.

We predict smaller motor priming effects for the physically impossible as compared to the physically possible movement condition after directing attention to the physically impossible action. This prediction states that similar motor priming effects in our previous experiment were due to inattentional blindness or misinterpretation of the physically impossible finger lifting movement (passing the finger behind the brick).

METHOD

Participants. A new group of 25 undergraduate students (12 male, mean age: 23.2) participated in this experiment. All were right-handed, had normal or corrected-to-normal vision, and were naive with regard to the hypotheses of the experiment. Participants were paid 7 for their participation.

Apparatus and Stimuli. Apparatus and Stimuli were modified as compared to the previous experiment. The finger movements of the model were taken from a female model presented on the screen with approximately the same dimensions as in the previous experiment. Again, we presented finger movements of a left hand positioned to mirror a participant's response hand (see Figure 4). The hands were now presented from a slightly different angle, guaranteeing a perfect view of the moving fingers with respect to the physical context. As in our previous experiment, we presented two types of movements (*Physically Impossible* and *Physically Possible movements*). In contrast to our previous experiment, only finger-lifting movements were presented in which either the index finger or the middle finger was lifted with or without a constraint. The movement kinematics of the presented action were the same for Possible and Impossible movements. Both conditions differed

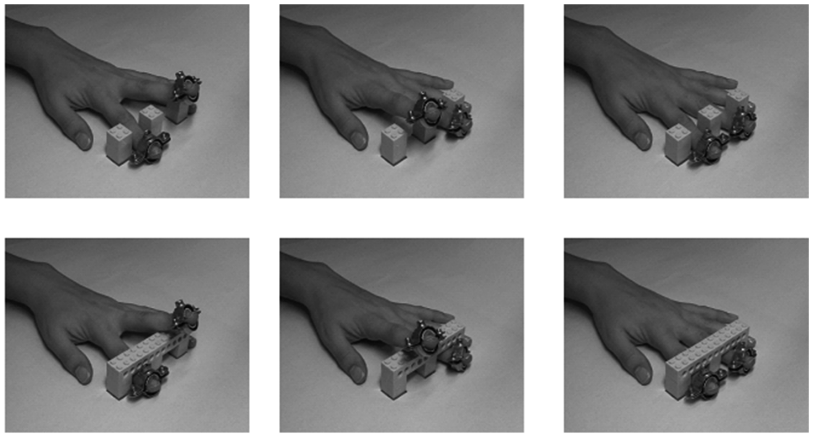

FIGURE 4. Physically possible, non-constrained (upper row) and physically impossible, constrained (lower row) in neutral (right), index finger lift (middle) and middle finger lift (left) conditions of Experiment 2.

only with respect to action context. A metal clamp was added around the moving fingers (index and middle finger). Reaction times were recorded with the help of a response device which detected the lifting movement using optical sensors.

Procedure and Design. The procedure and design were identical to the previous experiment. In total 320 trials were given in two blocks, with a short break between blocks. Each participant performed 160 trials of each movement type. In one block participants had to respond in an imitative way, in the other block in a contra-imitative way. Block order was counterbalanced across participants.

RESULTS

The same procedure as in the previous experiment was applied to the data set from Experiment 2. This resulted in the exclusion of 2.2% of trials from the RT data analysis. RTs and percentage error for Possible movements and Impossible movements are presented in Figure 5.

RT Analysis. We used a 2 x 2-factorial design to analyze the data, including the 2-level factor *Physical possibility* (Possible movements, Impossible movements) and the 2-level factor *Congruency* (congruent, incongruent), both as within-subject variables to analyze RT and accuracy data. We found general faster RTs for Possible movements than for Impossible movements (see Figure 5), as indicated by a significant effect of *Physical possibility,* $F(1, 24) = 41.24$, $MSe = 80.01$, $p < .001$, partial $\eta^2 = .63$. RTs for incongruent trials were slower, compared to congruent trials, as indicated by an effect of *Congruency*, $F(1, 24) = 222.91$, $MSe = 1820.58$, $p < .001$, partial $\eta^2 = .90$. The congruency effect did not differ for Possible and Impossible movements, as indicated by a nonsignificant interaction of *Physical possibility x Congruency,* ($F < 1$), partial $\eta^2 = .01$.

Planned *t*-tests indicated a large congruency effect for Possible movements amounting to 126 ms, $t(24) = -14.42$, $p < .001$. For Impossible movements, we also observed a large congruency effect of 129 ms, $t(24) = -14.46$, $p < .001$. For an over-

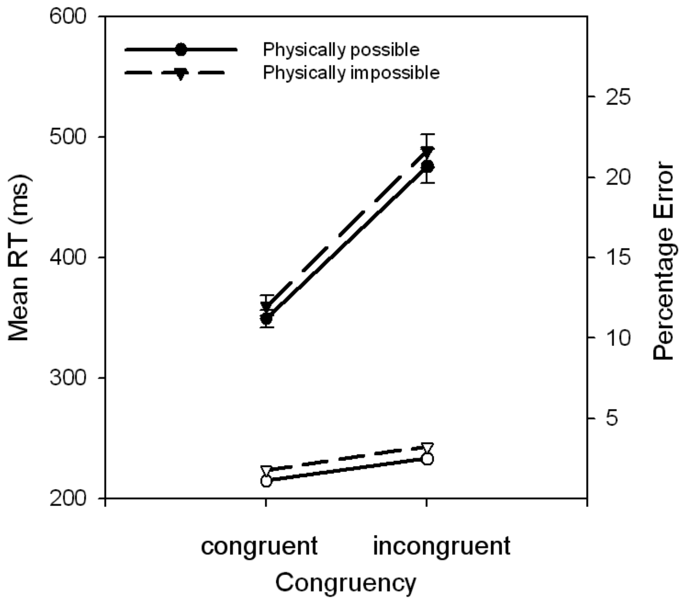

FIGURE 5. Mean reaction times (RTs) in milliseconds (ms) with error bars representing standard errors of the mean (filled s`ymbols) and percentage error (unfilled symbols) for Experiment 2, as a function of observed movement type (physically possible and physically impossible movements) and congruency (congruent and incongruent).

view of RTs and percent errors in congruent and incongruent conditions of Experiment 2 including main effects see Table 2.

Error Analysis. Error analysis showed that errors for different types of observed movements did differ. We observed a significant main effect of *Physical possibility*, $F(1, 24) = 5.53$, $MSe = 2.34$, $p < .05$, partial $\eta^2 = .19$, due to increased error rates in the Impossible movement condition. Participants made more errors in incongruent compared to congruent trials, indicated by an effect of *Congruency*, $F(1, 24) = 12.15$, $MSe = 4.07$, $p < .05$, partial $\eta^2 = .34$. However, the congruency effect did not differ for different types of observed movements, indicated by a nonsignificant interaction of *Physical possibility x Congruency* ($F < 1$). The error pattern confirmed that the RT results can not be attributed to an SAT.

DISCUSSION

In Experiment 2, we investigated whether inattentional blindness for biophysically impossible actions was the reason for the absence of any differences in automatic imitation between physically possible and impossible actions. After directing participant's attention to the way the movement was performed and controlling for alternative action interpretations we found a large motor priming effect for physically possible actions. We also found a large motor priming effect for physically impossible actions. Contrary to our predictions, both effects did not differ in size. This time the motor priming effect was even numerically larger in the impossible condition. This suggests a general insensitivity of the automatic imitation system to physical-

TABLE 2. Mean reaction times (RTs) in milliseconds (ms) and percent errors (upper part) are shown for physically possible (non-constrained) and physically impossible (constrained) movement conditions of Experiment 2. Corresponding *p*-values for within-subjects effects (lower part) are shown separately for RTs and percent errors.

Condition	RT (ms)	Error (%)
Congruent possible	350	1,1
Congruent impossible	360	1,8
Incongruent possible	476	2,5
Incongruent impossible	488	3,3
Within subjects	***p*(RT)**	***p*(Error)**
Congruency (C)	<.001*	.002*
Physical possibility (P)	<.001*	.027*
C x P	.628	.892

Note. *sign ($p < .05$)

action plausibility. With the present findings, we can rule out an inattentional blindness interpretation (Mack & Rock, 1998) for the findings of Experiment 1.

Given the present results, one potential interpretation could be that perceived actions are coded at the goal level (Bekkering et al., 2000). However, even after focusing attention on the movements, we found no differences in automatic imitation between physically possible and impossible movements.

GENERAL DISCUSSION

Humans have an automatic imitative response tendency when they observe other people performing actions (Brass et al., 2000, 2001; Chartrand & Bargh, 1999). We tested the sensitivity of the automatic imitation system to physical plausibility by comparing motor priming effects for physically possible and physically impossible actions. Using a choice-reaction task paradigm requiring imitative and contra-imitative responses (Experiment 1), we found a significant motor priming effect for physically possible and also for physically impossible movements. Both effects did not differ statistically. The finding of almost identical motor priming effects in Experiment 1, however, could be explained by a reinterpretation of the impossible movement in a biologically possible way (Shiffrar & Freyd, 1990). To rule out this alternative interpretation, we developed new stimulus material. In Experiment 2, we put a clamp on the fingers observed, constraining the observed movements in a physically impossible way, ruling out alternative action interpretations for previous findings. Furthermore, we directed attention to the way the movement was performed (physically possible and physically impossible), ruling out an inattentional-blindness interpretation (Longo et al., 2008; Mack & Rock, 1998). Even after including this attentional manipulation, which has effectively been used to induce effects on automatic imitation by manipulating biological plausibility and attributed intentionality (Liepelt et al., 2008; Longo et al., 2008; Stanley et al., 2007), we replicated our previous findings that physical plausibility has no influence on motor priming. The only difference we observed between physically possible and impossible movements was a main effect of physical possibility in both experiments. This finding might be interpreted in terms of a representation of the barrier in the simulation system which is unspecific to the congruency of the movement (Liepelt et al., 2009). However, such a main effect is difficult to interpret, because it might merely represent perceptual slowing due to the presence of the barrier in the physically impossible condition.

Differences in effect sizes between experiments can probably be explained by the different responses which were required in each experiment. Index- and middle-finger responses (Experiment 2), for example, can be performed simultaneously while this is not the case for a lifting and a tapping movement of the index finger (Experiment 1).

THE MIRROR SYSTEM AND PHYSICAL PLAUSIBILITY

While we are aware of the fact that our conclusions are based on a null result, we believe that we can nevertheless make a strong case for the lack of influence of physical plausibility on automatic imitation. Our data suggest that, as long as an action is perceived as biologically possible and is executed by an intentional agent, physical plausibility seems to be ignored. From an evolutionary point of view, ignoring the physical plausibility in the context of automatic imitation makes sense. One potential function of the mirror system is the prediction of events in the environment (Wilson & Knoblich, 2005). From this functional perspective, it is crucial to know if a specific behavior is intended or not and whether a change in the environment is caused by a biological agent or not. However, whether something is physically possible or not is functionally irrelevant for action prediction, because physically impossible actions usually never occur in real-life environment. This suggests that we represent physical plausibility in the context of observed behavior not in an embodied way but in a rather abstract way, providing indirect support for the notion that the mirror system is primarily a social system.

AUTOMATIC IMITATION AS A GOAL-DIRECTED PROCESS AND THEORY OF EVENT CODING

One possible interpretation of the present findings might be related to the goal-directed nature of imitation (Bekkering et al., 2000). When observing a movement, the movement goal is extracted and the system ignores the physical plausibility of the movement path. Such an explanation would be in line with recent findings showing that action goals can trigger motor priming effects (Liepelt et al., 2008; Longo et al., 2008). Furthermore, work by Stürmer and colleagues showed that perceiving the end state of an action is sufficient to elicit automatic imitation (Stürmer, Aschersleben, & Prinz, 2000).

On a more theoretical perspective it is assumed that actions can be coded on different levels (Hommel, Müsseler, Aschersleben, & Prinz, 2001). Which codes are used for mapping observed actions to corresponding action schemes in the observer can be determined by attentional weighting of stimulus features (Longo et al., 2008), a phenomenon that has been proposed for spatial compatibility effects (Hommel, 2006; Hommel et al., 2001). As shown in the present study, however, changes in physical plausibility of a perceived action in relation to context are relatively robust against attentional weighting effects. These findings are consistent with Theory of Event Coding (TEC), assuming that actions are represented in terms of their perceived effects (James, 1890; Lotze, 1852; Prinz, 1990, 1997) that are established through correlated experience (Heyes, Bird, Johnson, & Haggard, 2005). Therefore, it seems quite reasonable that humans perceive physically impossible movements in ways that are present in their action repertoire. To summarize, the present study shows that the distinction between physically possible and physically impossible actions is not done on the level of the mirror system. Furthermore, it provides further evidence for the social nature of the mirror system.

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