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Automatic Imitation of Biomechanically Possible and Impossible Actions: Effects of Priming Movements Versus Goals

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Recent behavioral, neuroimaging, and neurophysiological research suggests a common representational code mediating the observation and execution of actions; yet, the nature of this representational code is not well understood. The authors address this question by investigating (a) whether this observation-execution matching system (or mirror system) codes both the constituent movements of an action as well as its goal and (b) how such sensitivity is influenced by top-down effects of instructions. The authors tested the automatic imitation of observed finger actions while manipulating whether the movements were biomechanically possible or impossible, but holding the goal constant. When no mention was made of this difference (Experiment 1), comparable automatic imitation was elicited from possible and impossible actions, suggesting that the actions had been coded at the level of the goal. When attention was drawn to this difference (Experiment 2), however, only possible movements elicited automatic imitation. This sensitivity was specific to imitation, not affecting spatial stimulus–response compatibility (Experiment 3). These results suggest that automatic imitation is modulated by top-down influences, coding actions in terms of both movements and goals depending on the focus of attention.

Keywords: automatic imitation, mirror neurons, impossible actions

The ability to understand the actions and mental states of those around us is crucial for interacting effectively in one's social world. In recent years, the motor system has been directly implicated in the understanding of others' actions; observation of actions results in covert simulation, enabling the observer to copy and subsequently understand the actions, goals, and intentions of the other person (Rizzolatti, Fogassi, & Gallese, 2001). Complementary lines of behavioral, neuroimaging, and neurophysiological research suggest a common representational code mediating the observation and the planning or execution of action. Behaviorally, for example, this common code manifests itself in automatic imitation, the tendency of even healthy adults to reproduce observed actions completely unintentionally and automatically (Darwin, 1872/1965). Such effects have been documented in numerous recent controlled experimental situations (e.g., Bertenthal, Longo, & Kosobud, 2006; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Castiello, Lusher, Mari, Edwards, & Humphreys, 2002; Chartrand & Bargh, 1999; Edwards, Humphreys, & Castiello, 2003; Heyes, Bird, Johnson, & Haggard, 2005; Jonas et al., 2007; Longo, 2006; Longo & Bertenthal, 2006; Press, Bird, Flach, & Heyes, 2005; Vogt, Taylor, & Hopkins, 2003).

Attentional Weighting Effects on Common Coding

What is the basis for these shared representations? According to the *theory of event coding* (TEC) of Hommel, Müsseler, Aschersleben, and Prinz (2001), perceptual and motor events are coded in terms of a shared set of features. Although the degree of featural overlap between perceptual and motor events is often described as being a function of their similarity (e.g., Knoblich & Flach, 2003), Hommel et al. claimed that the salience of particular features will vary as a function of task, context, and the direction of attention. According to TEC, this feature weighting can be induced by both intentional and attentional influences, resulting from highlighting of features of the response and of the stimulus, respectively.

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An informative example of intentional weighting comes from an experiment by Hommel (1993), who instructed participants to press either a left-hand or right-hand key depending on the pitch of a tone presented to either the left or right ear. Pressing a button with the right hand led to the illumination of a light on the left and vice versa. The participants were instructed to either “press a left or right button” or “switch on a right or left light.” In both cases, the actual response was the same even though the goal or effect of the action differed as a function of the instruction. When the response was described in terms of pressing a button, a standard Simon effect was observed; right-hand responses were faster when the tone was presented to the right ear and vice versa. When the response was described in terms of illuminating the light, this pattern reversed; the compatibility effect depended on the location of the light, rather than on the location of the pressed button. Thus, whether attention was drawn to a more proximal (pressing the button) or a more distal (illuminating the light) aspect of the action determined whether the action was coded as leftward or rightward.

Memelink and Hommel (2006), similarly, used a two-dimensional Simon task in which spatial compatibility could vary along horizontal (left–right) and vertical (top–bottom) dimensions. This task was interleaved with a logically unrelated priming task that could involve either the horizontal or vertical dimension. The magnitude of the Simon effect was increased along the dimension suggested by the priming task. This result suggests that the relative weights of the horizontal and vertical dimensions were flexibly adjusted depending on the requirements of the task. Other studies using a similar two-dimensional Simon paradigm report that simply describing the response-keys using horizontal (i.e., “right” or ”left”) or vertical (i.e., “top” or ”bottom”) labels increases the magnitude of the Simon effect along the instructed dimension and reduces it along the uninstructed dimension (Hommel, 1996; Vu & Proctor, 2001, 2002; but see Memelink & Hommel, 2005). Even on a single-dimensional paradigm, Wenke, Nattkemper, and Frensch (2006) showed that the Simon effect was larger when participants were instructed to code responses spatially than when they were instructed to code responses as blue versus green. Similar to the preceding tasks, Wenke and Frensch (2005) found interference between concurrent verbal and manual tasks, but only when the same labels were used to describe the responses in both dimensions.

The Simon effect is only one of a number of different examples of stimulus–response (S-R) compatibility. Other dimensions besides spatial location can overlap and result in a response time advantage (e.g., Kornblum, Hasbroucq, & Osman, 1990). Thus far, most studies investigating the effects of intentional–attentional weighting on S-R compatibility have utilized Simon tasks. Although these studies find unequivocal evidence that the attentional focus or intentions of the participant influence spatial S-R compatibility, it is not clear what role intentional–attentional factors play in other S-R compatibility effects, such as automatic imitation. One suggestive study by Lakin and Chartrand (2003) found that priming participants with words related to affiliation and rapport increased the frequency of behavioral mimicry, presumably because mimicry increases affiliative tendencies and vice versa (Chartrand & Bargh, 1999).

A few neuroimaging studies are also relevant to this issue. Iacoboni and colleagues (2005) found that the activation of premotor mirror areas in the human brain was modulated by the behavioral context in which an action was embedded, arguing that the intention of the perceived act was coded, not just the goal. Interestingly, this result was not affected by instructing participants to attend to the object and infer the intention of the actor. From this lack of sensitivity to instructions, Iacoboni and colleagues (2005) suggested “that top-down influences are unlikely to modulate the activity of mirror neuron areas” (p. 532). This conclusion, however, is difficult to reconcile with other findings suggesting that instructions can modulate mirror system activation. Grèzes, Costes, and Decety (1998) found increased premotor activation in response to action observation when participants were told they would subsequently imitate the action as opposed to simply watch the action. Similarly, Zentgraf and colleagues (2005) told participants that after the study they would either imagine performing or evaluate the quality of observed gymnastics sequences, and they found greater activation in both frontal and parietal mirror areas in the imagery than in the evaluation condition.

Overall, these imaging studies of the human mirror system do not yield a consistent picture of the effects of top-down influences on motor responses following the perception of an action. Furthermore, it is difficult to translate the results from these neuroimaging studies into behavioral effects. The present study was designed to provide a more direct test of the effects of attentional weighting on automatic imitation by testing whether explicitly directing attention to the movements of a perceived action would affect the likelihood of eliciting automatic imitation based on goals versus movements.

Common Coding of Movements Versus Goals

Actions are coded at multiple, hierarchically nested levels of representation, ranging from activation of specific muscles to direction of movement to goal completion (Arbib, 1985; Jeannerod, 1997; Kakei, Hoffman, & Strick, 1999). As Hommel (2006) wrote:

> Every action we perform can be described in many ways and with regard to many levels: The same movement of one’s hand may be described in terms of the muscle movements involved, with regard to the emerging kinematic pattern, as the “signing of a contract,” or with respect to the socially defined meaning this signature has in the given context. (p. 168)

Humans are able to imitate actions at multiple levels, either in terms of goals (or effects) or of movements (e.g., Koffka, 1921/1959; Miller & Dollard, 1941; Morgan, 1900; Stränger & Hommel, 1995), behaviors associated with different patterns of neural activity (Chaminade, Meltzoff, & Decety, 2002). Nevertheless, prevalence is often attributed to goals (e.g., Bekkering, Wohlschläger, & Gattis, 2000; Prinz, 2002; Wohlschläger, Gattis, & Bekkering, 2003). Wohlschläger et al. (2003), for example, suggested that “it is primarily the goal of an act that is imitated; how that goal is achieved is only of secondary interest” (p. 502). In line with this focus on goals in imitation, theories of common coding generally agree that matching of perceived and produced actions occurs primarily or exclusively at the level of distal effects or goals[1] (e.g., Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 2002; Wohlschläger et al., 2003). Similarly, mirror neurons in monkeys selectively code actions at the level of goals (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996), sometimes responding only to those actions that fit the appropriate behavioral context (Fogassi et al., 2005).

In the context of this discussion, it is important to distinguish the ability of humans to imitate actions from the tendency of humans to automatically imitate observed actions (e.g., Koffka, 1924/1959; McDougall, 1908; Morgan, 1900; Stränger & Hommel, 1995). The studies of Bekkering, Wohlschläger, and colleagues (e.g., Bekkering et al., 2000; Wohlschläger & Bekkering, 2002; Wohlschläger et al., 2003) have found goals to be of particular importance in cases in which participants were explicitly instructed to imitate what a model did. By contrast, it is not clear whether it is goals or movements that play a role in the automatic tendency of people to imitate observed actions. In many tasks, it is difficult to isolate the effects of movements because they typically covary with goals. Holding and squeezing an orange, for example, differ both in terms of movements and goals. Thus, differences in the manner of movement are typically confounded by differences in the goal of the movement.

Recently, a few authors have suggested that, at least in humans, movements may play a larger role in the representation of perceived actions than had previously been supposed. Rizzolatti, Fadiga, Fogassi, and Gallese (2002), for example, speculated that two distinct "resonance mechanisms" may underlie imitation in humans: a high-level resonance mechanism coding action in terms of goals, and a low-level resonance mechanism sensitive to the movements constituting an action. Lyons, Santos, and Keil (2006) similarly suggested that the mirror system in monkeys may code perceived actions only in terms of their goals or underlying intentions, whereas the human mirror system codes actions more flexibly and at multiple levels of abstraction, both in terms of goals and the manner in which those goals are achieved. A similar view was put forward by Rizzolatti and Craighero (2004).

Some preliminary evidence supporting this interpretation that the human mirror system represents movements in addition to goals comes from a series of studies by Gangitano, Mottaghy, and Pascual-Leone (2001, 2004), who applied transcranial magnetic stimulation (TMS) to motor cortex as participants watched a hand reach and grasp an object. By manipulating when in the time course of the grasp TMS was applied, they demonstrated that the motor evoked potentials recorded from arm muscles varied systematically with the finger aperture over the course of the reach. This finding thus suggests that the mental simulation of the observed action included the manner in which the action is performed over time and does not exclusively represent the goal or end state.

The Present Study

The goal of the present study was to examine the role of attentional weighting in automatic imitation. In particular, we investigated how directing attention to the manner in which actions were performed affects the relative influence of goals and movements in the common coding of perceived and produced actions. The basic logic was to present actions that are either biomechanically possible or impossible in terms of movements but which are identical in terms of goals (i.e., tapping a surface; see Figure 1). If the actions are coded in terms of goals, comparable levels of automatic imitation should be elicited from both types of action, because the goals are the same. If, in contrast, the actions are coded in terms of their constituent movements, automatic imitation should be attenuated for the impossible actions compared with the possible ones, given that actions that are physically difficult or impossible to perform (e.g., moving a hand through another body part) or are not performed by the observer (e.g., ballet dancing) are less likely to activate cortical areas associated with the mirror system (Buccino et al., 2004; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Stevens, Fonlupt, Shiffrar, & Decety, 2000).

Automatic imitation was measured with an S-R compatibility paradigm developed previously (Bertenthal et al., 2006), adapted from a task used by Brass and colleagues (2000). Participants were presented with two-frame apparent motion stimuli showing either the index or middle finger of a right or a left hand moving down and tapping a surface. They were instructed to respond to the relative spatial position of the index and middle fingers by pressing a button with their right index finger if the stimulus finger appearing to the left moved and to respond with their right middle finger if the finger appearing to the right moved. When a left-hand stimulus was presented, the response finger matched the stimulus finger anatomically (see Figure 1); participants responded to an index finger movement with their index finger and to a middle finger movement with their middle finger (anatomically compatible condition). When a right-hand stimulus was presented, this pattern was reversed; participants responded to an index finger movement with their middle finger and to a middle finger movement with their index finger (anatomically incompatible condition). If automatic imitation of the anatomically matching finger occurs, responses should be faster to the compatible (left-hand) stimulus than to the incompatible (right-hand) stimulus, the pattern observed in our earlier study (Bertenthal et al., 2006). Participants were instructed only to respond to the spatial cue; no mention whatsoever was made of imitation.

In our original study (Bertenthal et al., 2006), we elicited automatic imitation using a video image of a human hand; in the present study, we used a computer-generated graphical hand. The use of a virtual hand allows presentation of biomechanically impossible finger movements, which were needed for the current investigation. We recently found that such a computer-generated hand elicits comparable automatic imitation as a video image of an actual hand (Longo, 2006).[2]

Three experiments were conducted. Experiment 1 compared automatic imitation of biomechanically possible and impossible finger movements without mentioning anything about the presence of impossible movements, allowing us to investigate how actions are spontaneously coded. Experiment 2 investigated the effects of attentional weighting on automatic imitation. Participants were explicitly told at the beginning of the experiment

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[1] The term *goal* is sometimes equated with the term *intention*. In this article, a *goal* will refer exclusively to the distal effect or the end state of the action and not to some motivation for the action.

[2] Such effects were found, at least, when attention was not overtly drawn to the artificiality of the virtual hand.

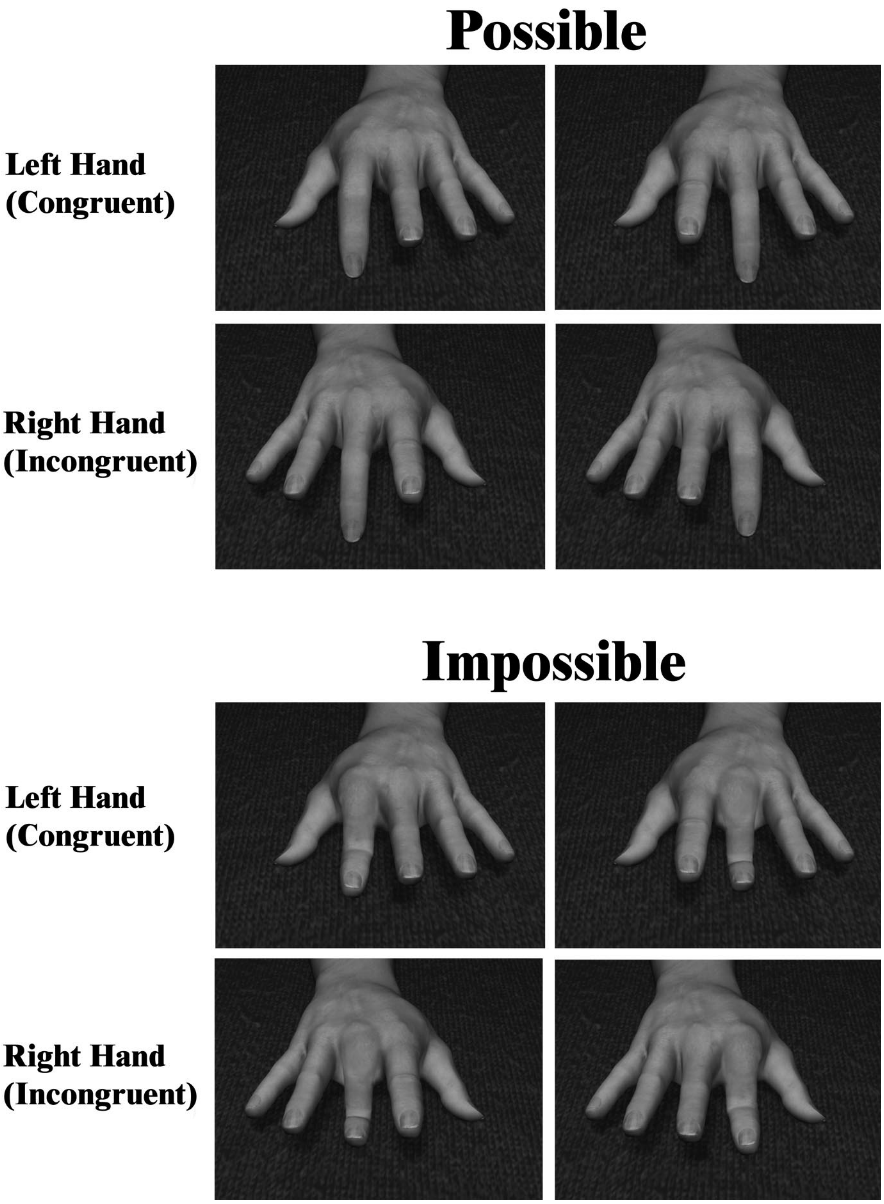

Figure 1. Stimuli used in the experiments. Only the final frame of each animation is shown. The top panel displays the possible movements, and the bottom panel displays the impossible movements. Within each panel, the top row displays the finger movements compatible with the participants' responses; the bottom row displays the finger movement incompatible with the participants' responses.

that they would see both "natural" and "impossible" finger movements to direct attention to the manner in which the actions were performed. Experiment 3 was designed as a control to make sure that differences observed between the first two experiments did not result from participants being distracted by the novelty of the impossible finger movements and also to examine whether sensitivity to the manner in which an action was performed would generalize to another form of S-R compatibility, specifically spatial compatibility (cf. Simon, 1969), which would not be expected to be influenced by the biomechanics of a perceived action.

Experiment 1

The first experiment tested the sensitivity of automatic imitation to possible and impossible finger movements without any mention of this distinction. As previously discussed, it is still unclear whether people show a tendency to automatically imitate goals or movements of observed actions. If actions are coded in terms of goals, comparable imitation should be elicited from both possible and impossible movements. If, however, actions are coded in terms of movements, imitation should be reduced or eliminated when the movements are biomechanically impossible, because the match between observed and executed actions will have diminished in this condition.

Method

Participants. Twenty-four students at the University of Chicago (15 female; 9 male) between 18 and 34 years of age participated. All were right-handed, as determined by the Edinburgh Inventory (Oldfield, 1971; $M = 83.20$, range: 44.44–100), naive as to the purpose of the study, and were paid $8 for their participation. An additional 5 participants were excluded from analyses due to error rates exceeding 25%. Given the simplicity of the task, the large number of participants eliminated due to high error rates deserves some comment. Error rates for these 5 participants were extremely high in the incompatible condition (79.25%) but quite low in the compatible condition (5.00%). This suggests that even though the experimenter observed performance during practice trials to make sure the task was done correctly, participants subsequently switched from responding on the basis of the relative spatial position of the moving finger to responding on the basis of the anatomically identity of the finger. That is, they were not really making a large proportion of errors per se but were responding systematically to the wrong dimension of the stimulus. Even though the spatial dimension of the fingers leads to a larger priming effect than does anatomical identity (Bertenthal et al., 2006), participants seem to find it more natural to respond to the identity—intentionally imitating the hand—than to the spatial position. This pattern of errors is consistent with a strong automatic tendency of people to imitate observed actions.

An additional 8 volunteers at University College London (4 female; 4 male), between 18 and 35 years of age, rated the stimuli but did not complete the full paradigm.

Apparatus and materials. Stimuli were displayed on a 43.2-cm computer monitor. Participants were seated at a comfortable distance approximately 60 cm from the monitor. The hand displayed on the screen measured a visual angle 13.3° horizontally and 10° vertically and was embedded in a blue rectangular region measuring approximately 20° × 13.3°. The displacement of the moving index and middle fingers was approximately 1.9° of visual angle. E-Prime software (Psychology Software Tools, Pittsburgh, PA) was used for stimulus presentation and data collection.

The computer-generated hand and arm were created from a high-resolution three-dimensional mesh model (purchased from Viewpoint, New York, NY) consisting of approximately 200,000 polygons and 16 vertices. After creating the structure and texture of the hand, we imported the model into 3D Studio Max (Autodesk, San Rafael, CA) and added 22 bones from the upper shoulder to the tip of the fingers. The bones were sized to the mesh model, and then each bone was connected in order starting from the finger tips and ending at the shoulder. Rotation points were positioned at each of the joints, and inverse kinematics solvers were added to create biomechanically realistic movements for the fingers, hand, wrist, elbow, and shoulders. The movement was accomplished by either a flexion of the finger at the metacaropo-phalangeal joint (possible movement) or by a flexion of the finger at the metacaropo-phalangeal joint in combination with a greater than 90° hyperextension of the finger at the proximal interphalangeal joint (impossible movement). The 3D model was then positioned in a visual scene consisting of a homogeneous flat blue surface, and lighting and cameras were positioned to illuminate the hand and create faint shadows of the fingers (see Figure 1).

Ratings of the stimuli were obtained from 8 participants (4 female; 4 male). Participants were shown the eight finger movements used in the experiments formed by crossing hand (left, right), finger (index, middle), and possibility (impossible, possible). Order of finger movements was randomized. They were told that they would see short clips of finger movements and, after each, would be asked to rate their agreement with several statements (listed in Figure 2). Ratings were made on a 7-point Likert scale with anchors 3 (*strongly agreed*), –3 (*strongly disagreed*), and 0 (*neither agreed nor disagreed*). The statements were read by the experimenter, and responses were made verbally.

Design and procedure. Participants in the main experiment were instructed to respond by pressing the *1* or *3* keys on the number pad of a keyboard with the index or middle finger, respectively, of their right hand in response to the relative spatial position (left–right) of the index and middle fingers of the stimulus hand. The experiment consisted of 16 blocks of 20 trials, 10 each of index and middle finger movements. Blocks alternated between left and right hands and (every other block) between possible and impossible finger movements. Order of blocks was counterbalanced across participants. Experimental trials were preceded by practice blocks of the four conditions (each consisting of 20 trials), which were not included in analyses.

Each trial began with a frame lasting 533 ms showing the hand at rest. The second frame showed one of the fingers having moved down and resting on the table. There was no interstimulus interval. This frame lasted 1,000 ms and was followed by a blue screen lasting 1,467 ms. Thus, each trial lasted a total of 3 s.

Results and Discussion

Two questions are addressed in this section. The first concerns whether the two computer-generated finger tapping events were differentiable in terms of one appearing consistent with a possible biomechanical movement and the other appearing consistent with an impossible biomechanical movement. The second question concerns whether automatic imitation would be elicited by both possible and impossible finger movements.

Stimuli ratings. Stimuli were rated by the 8 participants who did not participate in the main experiment. Ratings of the stimuli are shown in Figure 2. Participants strongly agreed that the possible finger movements looked like an action they could perform themselves ($M = 2.91$), $t(7) = 44.19$, $p < .0001$; like an action that most people could perform ($M = 2.91$), $t(7) = 44.19$, $p < .0001$; and that the finger movement looked natural ($M = 2.52$), $t(7) = 9.25$, $p < .0001$. They strongly disagreed that the possible finger movement looked like something they could not do ($M = –2.94$), $t(7) = –71.79$, $p < .0001$; and that the finger looked broken ($M = –2.78$), $t(7) = –23.20$, $p < .0001$. In contrast, participants strongly disagreed that the impossible finger movements looked like an action they could perform themselves ($M = –2.09$), $t(7) = –3.10$, $p < .02$; like an action most people could perform ($M = –2.28$), $t(7) = –6.06$, $p < .001$; and that the finger movement looked natural ($M = –2.59$), $t(7) = –13.75$, $p < .0001$. They strongly agreed, however, that the impossible finger movements looked like something they could not do ($M = 2.03$), $t(7) = 3.14$, $p < .02$; and that the finger looked broken ($M = 2.41$), $t(7) = 9.01$, $p < .0001$.

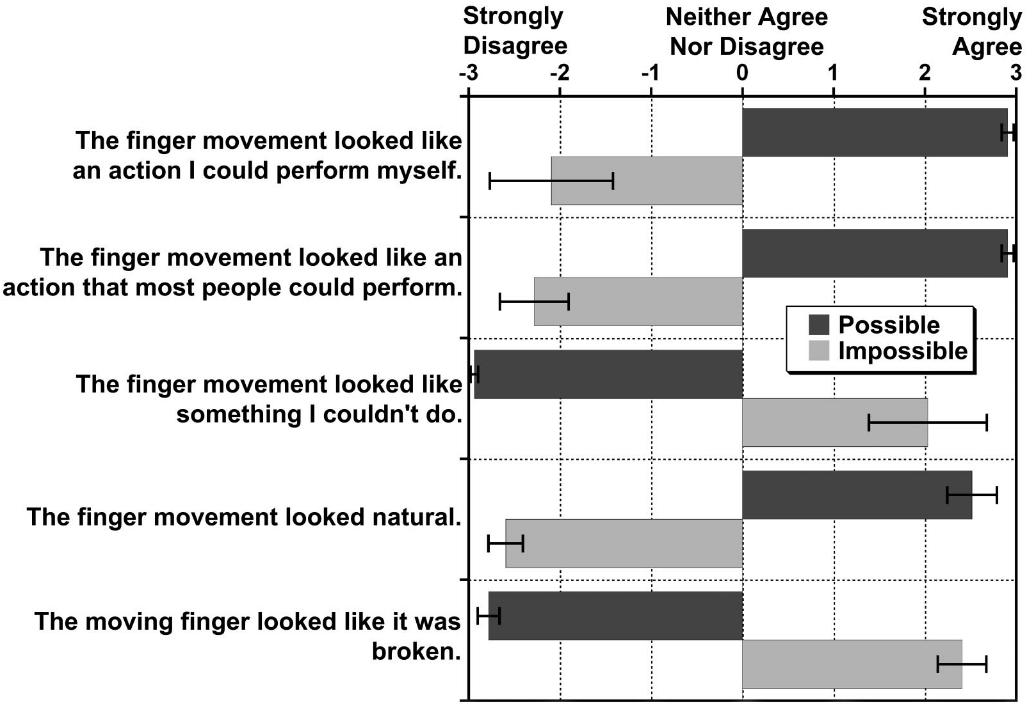

Figure 2. Mean ratings of the stimuli. Error bars represent standard errors of the mean.

These ratings provide strong evidence that the manipulation of possible versus impossible movements was successful. Participants overwhelmingly rated the possible movements as looking like natural actions they and others could perform and the impossible movements as unnatural actions with broken fingers that neither they nor others could perform. These ratings were unanimous with the single exception of 1 participant who claimed to be triple jointed and rated the impossible finger movements as something that he—but not people generally—could do. He agreed that the impossibly moving finger looked broken and disagreed that it looked natural. For this reason, participants in all experiments who claimed to be double jointed or triple jointed were excluded from analyses.

Main experiment. A repeated-measures analysis of variance (ANOVA) was conducted on mean response time (RT), with compatibility (compatible, incompatible) and movement (possible, impossible) as variables. Error trials and trials in which RT was faster than 200 ms or slower than 1,000 ms were excluded from analysis. There was a significant compatibility effect, $F(1, 23) = 9.71$, $p < .01$, $\eta_p^2 = .297$ (see Figure 3); RTs were faster to anatomically compatible (313.05 ms) than incompatible (320.56 ms) finger movements, indicating that participants automatically imitated the actions, replicating the finding of Bertenthal et al. (2006). RT was comparable with possible (315.85 ms) and impossible (317.76) movements, $F(1, 23) = 0.67$, *ns*, $\eta_p^2 = .028$, and there was no significant interaction between movement and compatibility, $F(1, 23) = 0.04$, *ns*, $\eta_p^2 = .002$. Planned comparisons revealed significant compatibility effects for both possible (7.08 ms), $t(23) = 2.72$, $p < .02$, and impossible (7.95 ms), $t(23) = 2.07$, $p < .05$, finger movements (see Figure 2), which did not differ significantly, $t(23) = 0.20$, *ns.*

Errors were made on 3.41% of trials, and 1.35% of trials were excluded because of an RT less than 200 ms or exceeding 1,000 ms. The pattern of errors mirrored that of RTs, though there were no significant differences between conditions.

Comparable automatic imitation was elicited from both possible and impossible movement, suggesting that finger movements were coded in terms of the goal (i.e., tapping a surface), as suggested by common coding theorists (e.g., Hommel et al., 2001; Prinz, 2002).

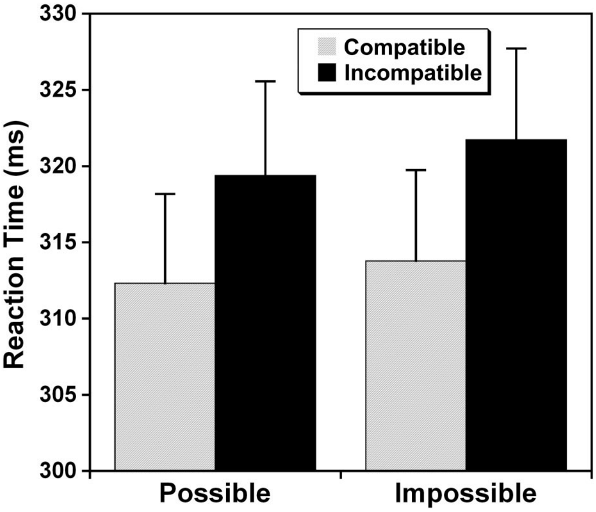

Figure 3. Mean reaction times (in milliseconds) in Experiment 1 as a function of compatibility (compatible or incompatible) and movement type (possible or impossible). Error bars represent standard errors of the mean.

This insensitivity to the difference in movements is consistent with recent neuroimaging and physiological evidence presented by Aglioti and colleagues (Costantini et al., 2005; Romani, Cesari, Urgesi, Facchini, & Aglioti, 2005). Using functional magnetic resonance imaging (fMRI), these researchers found similar activation of premotor mirror system regions elicited from observation of biomechanically possible and impossible actions (Costantini et al., 2005); while using TMS, they found similar cortio-spinal excitability elicited by the observation of possible and impossible finger movements (Romani et al., 2005). Although several studies have found that actions that are not in one's motor repertoire at all (e.g., ballet moves) activate the human mirror system less that those that are (e.g., Calvo-Merino et al., 2005, 2006), the present results and those of Aglioti and colleagues suggest that this is not the case when actions are impossible only in the manner in which they are performed. This pattern is consistent with the central role of goals in the representation of actions.

Although these results reveal no apparent sensitivity of common coding mechanisms to the differences between possible and impossible movements, it is conceivable given the evidence reviewed in the introduction that this sensitivity is modulated by the significance of the stimulus information or the direction of attention. In the main experiment, it was only necessary to attend to the outcome of the finger movement; the manner in which the action was performed was irrelevant to the task. Indeed, a few of these participants reported not even noticing anything unusual about the impossible finger movements and, of those who did notice, several commented on the strangeness of some movements but were unable to describe precisely what it was that was aberrant. Participants who explicitly rated the stimuli, however, clearly judged the possible actions as possible and the impossible actions as impossible. These findings suggest that when attention was not directed to the manner in which actions were performed, they were perceived exclusively at the level of goals, and participants showed a form of inattentional blindness to the manner in which the actions were performed (cf. Mack & Rock, 1998). Thus, although participants in this experiment appeared to code actions in terms of goals, it is possible that drawing attention to the manner in which the actions are performed would shift the representation involved in automatic imitation from the level of goals to that of movements.

Experiment 2

The second experiment was designed to explicitly test whether a change in attentional focus from goals to movements would shift participants tendencies to imitate movements instead of goals. Participants were told at the beginning of the experiment that they would see both natural and impossible finger movements. Given that similar manipulations (Memelink & Hommel, 2006) have been shown to shift the attentional weighting of stimulus dimensions, we hypothesized that the new instructions should have the effect of increasing the attentional weighting of movements—relative to goals—and should lead to a reduction in the effects of automatic imitation following observation of impossible finger movements. That is, attentional weighting may serve to highlight the specific movements of a perceived action even though the tendency to imitate actions at the level of movements would not occur spontaneously.

Method

Participants. A new sample of 24 University of Chicago students (15 female; 9 male) between 18 and 34 years of age participated. All were right-handed as determined by the Edinburgh Inventory (M = 78.66, range: 50–100), naive as to the purpose of the study, and were paid $8 for their participation. An additional 4 participants were excluded from analyses, 1 because of an error rate exceeding 25%, 2 who claimed to be double jointed, and 1 who claimed not to have noticed that there were two types of movement, clearly not having attended to the instructions.

Apparatus and materials. All materials were identical to those used in Experiment 1.

Design and procedure. Procedures were identical to those in Experiment 1, except that participants were told while being given instructions that some of the finger movements they would see were natural and some were impossible.

Results and Discussion

A repeated-measures ANOVA was conducted on mean RT, with compatibility (compatible, incompatible) and movement (possible, impossible) as variables. Error trials and trials in which the RT was faster than 200 ms or slower than 1,000 ms were excluded from analysis. The results revealed a significant compatibility effect, $F(1, 23) = 5.12, p < .05, \eta_p^2 = .182$ (see Figure 4); responses were faster to compatible (308.71 ms) than to incompatible (314.00) actions, again revealing an overall automatic imitation tendency. In contrast to Experiment 1, there was a significant interaction between compatibility and movement, $F(1, 23) = 7.75, p < .01, \eta_p^2 = .252$, indicating that the amount of automatic imitation was modulated by whether a possible or impossible action was observed. Whereas planned comparisons revealed automatic imitation in response to possible finger movements (9.65 ms), $t(23) = 3.92, p < .001$, no such effect was revealed in response to impossible finger movements (0.93 ms), $t(23) = 0.30$, *ns*; this difference

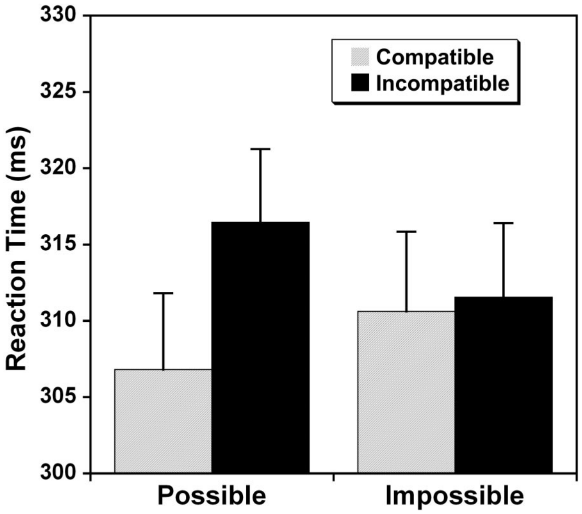

Figure 4. Mean reaction times (in milliseconds) in Experiment 2 as a function of compatibility (compatible or incompatible) and movement type (possible or impossible). Error bars represent standard errors of the mean.

between conditions was significant, $t(23) = 2.78$, $p < .02$ (see Figure 4). As in Experiment 1, overall RT (collapsed across compatible and incompatible trials) was comparable with possible (311.63 ms) and impossible (311.08 ms) actions, $F(1, 23) = 0.11$, *ns*, $\eta_p^2 = .005$.

Errors occurred on 2.25% of trials, and 1.43% of trials were excluded because of an RT under 200 ms or exceeding 1,000 ms. Significantly more errors were made on incompatible (2.68%) than on compatible (1.82%) trials, $t(23) = 2.10$, $p < .05$, mirroring the RT data, though this effect did not interact with the difference between possible and impossible movements, $t(23) = 0.59$, *ns.*

The effects of instructing participants about the presence of impossible finger movements was examined by comparing the difference in automatic imitation between possible and impossible movements between Experiments 1 and 2.[3] This difference was significantly greater in Experiment 2 (8.72 ms) than in Experiment 1 (−0.87 ms), $t(26) = 2.64$, $p < .02$, demonstrating that notifying participants that they would see the impossible movements had a significant influence on modulating the magnitude of automatic imitation.

These results suggest that common coding of actions can occur either at the level of goals or of movements depending on the direction of attention to different aspects of the action. It thus appears that attentional weighting of features operates similarly for automatic imitation (this study) and for other S-R tasks involving spatial compatibility (e.g., Memelink & Hommel, 2005). In Experiment 1, when participants were not cued to attend to the movements, the coding of actions appeared to be in terms of goals, as comparable automatic imitation was elicited by biomechanically possible and impossible movements. In Experiment 2, when participants' attention was drawn to the manner in which the movement was executed, differences in automatic imitation were found depending on whether the movement could be performed by the observer. Together, the results from these two experiments suggest that common coding can occur either at the level of goals or of movements depending on the direction of attention and the instructions given to participants, although coding at the level of goals appears to be the default response.

One potentially trivial explanation for the difference between Experiments 1 and 2 is that participants in Experiment 1 may simply not have noticed the impossible movements. As reported above, however, although a few participants in Experiment 1 did fail to notice the impossible movements, most did notice them. Furthermore, participants who were explicitly asked to judge whether the actions were possible strongly rated the impossible movements as impossible. Thus, the difference between Experiments 1 and 2 is better explained as a function of the level at which the actions were coded.

Another interpretation that needs to be considered is that the drawing of attention to the impossible movements in Experiment 2 led these movements to become distracting on account of their novelty and strangeness. If this interpretation was correct, the impossible movements may simply have been seen as weird or unusual, disrupting performance and leading to a ceiling effect that masked the automatic imitation effect. In this case, responses should have been slower to impossible, than to possible, actions. As we reported, however, the overall RTs did not differ significantly between the two conditions and were even slightly faster than those in Experiment 1. Moreover, RT on incompatible trials in this experiment was actually faster to impossible (311.55 ms) than to possible (316.45) actions, $t(23) = 2.12$, $p < .05$, implying that response to the impossible movements are not at ceiling. This pattern suggests the absence of a compatibility effect in the impossible finger movement condition, rather than higher RTs masking the effect. These considerations suggest that the novelty of the impossible actions cannot account for the lack of automatic imitation to impossible actions in this experiment. Nevertheless, in order to definitively rule out this possibility and test the generalizability of these effects, we conducted a third and final experiment.

Experiment 3

If the difference in automatic imitation of biomechanically possible and impossible movements observed in Experiment 2 is due to the unfamiliarity or strangeness of the impossible finger movements leading to a ceiling effect, this pattern should be observed independent of the task and affect other forms of S-R compatibility as well. If, however, modulation of the response in Experiment 2 was due to the impossibility of the actions, this sensitivity should be specific to automatic imitation. To examine this issue, in Experiment 3 we examined whether spatial S-R compatibility (cf. Simon, 1969) would be modulated by whether the stimuli were biomechanically possible or impossible. As the "leftness" or "rightness" of an action is unaffected by whether the constituent movements are biomechanically possible or impossible, spatial S-R compatibility should not be affected by that manipulation. As in Experiment 2, participants were told at the beginning of the experiment that they would see both natural and impossible finger movements.

Experiments 1 and 2 tested for response priming as a function of the anatomical match between the stimulus and response fingers by having participants respond on the basis of the relative spatial position of the fingers (analogous to Experiment 3b in the study of Bertenthal et al., 2006). This experiment, in contrast, tested for response priming as a function of the stimulus and response sharing the same spatial code; participants were instructed to make responses based on the anatomical identity of the moving finger (analogous to Experiment 3a in the study of Bertenthal et al.). In both cases, one dimension (spatial compatibility or anatomical compatibility) is held constant by making it the basis for response, allowing manipulation of the compatibility of the other dimension via presentation of either a left or a right hand.

Method

Participants. A new sample of 24 University of Chicago students (13 female; 11 male) between the ages of 18 and 28 participated. All were right-handed as determined by the Edinburgh Inventory ($M = 81.66$, range: 37.5–100), naive as to the purpose of the study, and were paid $8 for their participation. An additional 4 participants were excluded from analyses, 1 because of a computer error, 1 because of an error rate exceeding 25%, and 2 who claimed to be double jointed.

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[3] Because these distributions appeared to be heavy tailed, we used Yuen's (1974) *t* test for trimmed means, with 20% trimming (see Wilcox, 2005).

Apparatus and materials. All materials were identical to those used in Experiments 1 and 2.

Design and procedure. The procedure used in this experiment was almost identical to the second experiment and included the same instructions concerning the presentation of both natural and impossible finger movement. The one difference between the experiments was that participants were instructed to imitate the stimulus finger that moved by pressing the response button with their anatomically matching finger. Thus, participants responded to the observation of the index finger tapping by pressing the *1* key with their index finger, and they responded to the observation of the middle finger tapping by pressing the *3* key with their middle finger. When the left hand was presented, the correct response was spatially compatible with the observed moving finger (see Figure 1); the observed index finger corresponded to the left stimulus in the display and served as a prime for the participant's left response finger (i.e., the index finger). Similarly, the middle finger appeared on the right and served as a prime for the participants' right response finger (i.e., the middle finger). By contrast, when the right hand was presented, this pattern was reversed and the correct response was spatially incompatible with the stimulus finger.

Results and Discussion

A repeated-measures ANOVA was conducted on mean RT, with compatibility (compatible, incompatible) and movement (possible, impossible) as variables. Error trials and trials in which the RT was faster than 200 ms or slower than 1,000 ms were excluded from analysis. There was a significant effect of compatibility, $F(1, 23) = 178.45$, $p < .0001$, $\eta_p^2 = .886$ (see Figure 5); responses were faster to spatially compatible (341.23 ms) than incompatible (380.63 ms) finger movements. This indicates that a spatial code shared between stimulus and response facilitated performance, consistent with our prior findings using the same paradigm (Bertenthal et al., 2006, Experiment 3a) as well as a large body of research on spatial S-R compatibility. Like Experiment 1, and unlike Experiment 2, there was no interaction between movement and compatibility, $F(1, 23) = 0.09$, *ns*, $\eta_p^2 = .004$. Planned comparisons revealed very similar spatial compatibility effects in response to both possible (38.66 ms), $t(23) = 14.06$, $p < .0001$, and impossible (40.15 ms), $t(23) = 8.61$, $p < .0001$, finger movements (see Figure 4), which did not differ significantly, $t(23) = 0.31$, *ns.*

Unlike the first two experiments, participants in this experiment were intentionally imitating the finger movements on each trial. If the impossible finger movements were distracting, then it might have been expected that participants would be able to imitate the possible finger movements more quickly than the impossible ones. In contrast to this prediction, RTs were similar for possible (360 ms) and impossible (361 ms) actions, $F(1, 23) = 0.34$, *ns*, $\eta_p^2 = .014$. This was true as well when compatible, $t(23) = 0.18$, *ns*, and incompatible, $t(23) = 0.34$, *ns*, trials were examined separately with planned comparisons. Thus, although automatic imitation in Experiment 2 was sensitive to the difference between possible and impossible movements, the same was not true for intentional imitation in this experiment, even though the representation for movements was again primed by the instructions. This is suggestive of processing differences between automatic and deliberate forms of imitation, though, of course, it is difficult to make claims on the basis of a null result.

Errors were made on 5.81% of trials, and 1.91% of trials were excluded because of an RT under 200 ms or exceeding 1,000 ms. Significantly more errors were made on incompatible (8.26%) than on compatible (3.36%) trials, $t(23) = 6.16$, $p < .0001$. This difference was significant for both possible (5.05%), $t(23) = 5.05$, $p < .0001$, and impossible (4.74%) actions, $t(23) = 6.36$, $p < .0001$, but there was no significant difference between them, $t(23) = 0.41$, *ns.*

The difference in compatibility effects was significantly greater for automatic imitation in Experiment 2 than for spatial compatibility in this experiment,[4] $t(25) = 2.26$, $p < .05$, suggesting that the observation of impossible finger movements differentially affected automatic imitation and spatial compatibility.

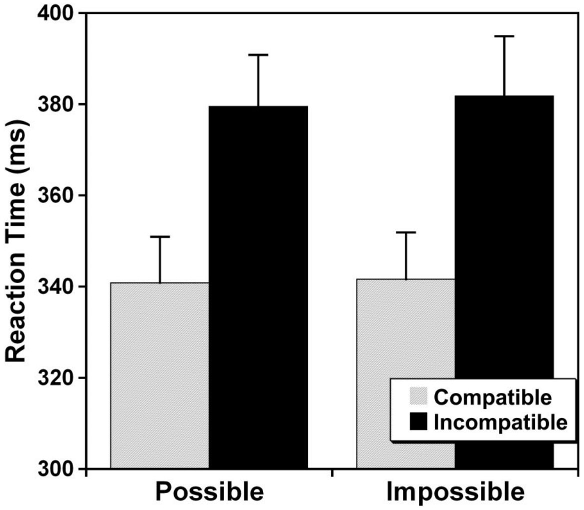

Figure 5. Mean reaction times (in milliseconds) in Experiment 3 as a function of compatibility (compatible or incompatible) and movement type (possible or impossible). Error bars represent standard errors of the mean.

General Discussion

The aim of this research was twofold: (a) to investigate the attentional weighting effects of instructions on automatic imitation and (b) to test whether common coding of an observed action is limited to the goal (or distal effect) of an action or is sensitive to movements as well. By manipulating the biomechanical possibility of the movement while holding the goal constant, we tested whether actions are automatically imitated at the level of goals or of movements. When the experimenter made no mention of the difference between possible and impossible actions, comparable automatic imitation was elicited from both types of action (Experiment 1), even though participants were generally aware of a difference. This suggests that the actions were coded at the level of goals (i.e., tapping a surface), rather than at the level of their constituent movements. When the experimenter instructed participants at the beginning of the experiment that they would see both

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[4] As with the comparison between Experiments 1 and 2, this comparison used Yuen's (1974) *t* test for trimmed means, with 20% trimming.

natural and biomechanically impossible actions, automatic imitation was eliminated for the impossible—but not the possible—actions (Experiment 2). This sensitivity to the manner in which the action was performed was specific to automatic imitation, not affecting spatial S-R compatibility (Experiment 3).

Attentional Weighting Effects on Automatic Imitation

As described in the introduction, numerous studies report that the magnitude of spatial S-R compatibility is affected by the manner in which responses are described to participants (e.g., Hommel, 1993; Memelink & Hommel, 2006; Vu & Proctor, 2001, 2002; Wenke & Frensch, 2005; Wenke et al., 2006), a phenomenon that Hommel et al. (2001) termed *intentional* or *attentional weighting* depending on whether the description modulated an aspect of the response or of the stimulus, respectively. The present results extend those findings in two ways. First, they show that similar weighting effects modulate automatic imitation. They dovetail in this respect with the recent findings of Bach, Peatfield, and Tipper (2007), who found that the degree of spatial attention to a body part affects the extent of automatic imitation elicited. Second, although Hommel (1993) demonstrated that spatial S-R compatibility could be manipulated by describing the participant's response action in different ways (intentional weighting of action), the present findings show a similar modulation of automatic imitation by describing the stimulus action differently (attentional weighting of action). This evidence suggests that common coding of action is not purely stimulus driven but is mediated by top-down influences. What matters is not the nature of the stimulus per se but how the stimulus is represented by the participant.

These results support the hypothesis of Rizzolatti et al. (2002) that both high- and low-level resonance mechanisms underlie imitation in humans. This resonance can occur at the level of movements as well as of goals. There is, however, a caveat to this conclusion. Although common coding occurred at multiple levels of representation, the default level appeared to be the goal of the action. This finding is consistent with other results suggesting the important role of goals in imitation (e.g., Wohlschläger et al., 2003). Even young infants appear to find the goal of an action, rather than the manner in which it is performed, most salient (Meltzoff, 1995; Woodward, 1998). Wohlschläger et al. (2003) do acknowledge that perceived actions may be coded in terms of their movements but only when they are not directed at a distal object. The present results, in contrast, suggest that explicit expectations and changes in attentional focus, rather than the presence or absence of an object, may determine whether high- or low-level resonance mechanisms are operative.

The present results also provide a bridge between two seemingly contradictory sets of findings. On the one hand, the behavioral results from Experiment 1 dovetail with recent fMRI (Costantini et al., 2005) and TMS (Romani et al., 2005) findings that biomechanically possible and impossible actions are coded similarly by mirror/common coding mechanisms; on the other, the results of Experiment 2 are consistent with recent behavioral (Casile & Giese, 2006), developmental (Longo & Bertenthal, 2006; Sommerville, Woodward, & Needham, 2005), and neuroimaging (Buccino et al., 2004; Calvo-Merino et al., 2005, 2006) studies relating the representation of perceived actions to the observer's own ability to perform the action. Calvo-Merino and colleagues (2006), for example, presented expert ballet dancers with examples of dance moves that either were in their own motor repertoire or were performed only by opposite-gender dancers, finding increased activation in mirror circuits for the same-gender moves. These actions differ qualitatively in terms of *what* actions they are; the possible and impossible stimuli used by Costantini et al. (2005) and Romani et al. (2005), in contrast, differ only in *how* the action is performed. Whereas it was obvious that different movements and actions were involved in the two ballet dances, the difference between the possible and impossible movements used in the latter two experiments was much less noticeable. The results from the current experiment show that automatic imitation is either sensitive (Experiment 2) or insensitive (Experiment 1) to whether an action is in the observer's motor repertoire depending on whether participants' attention is explicitly drawn to the manner in which the actions are performed.

The Automaticity of Automatic Imitation

According to traditional models of automaticity in cognitive psychology such as those of LaBerge and Samuels (1974), Posner and Snyder (1975), and Schneider and Shiffrin (1977), automatic processes generally share three primary characteristics: They are (a) capacity free and effortless, (b) stimulus driven, and (c) operate outside of awareness. The present findings showing the effects of attentional weighting on automatic imitation suggest that this process does not meet the second of these criteria. Thus, it is questionable as to whether what we have been calling *automatic imitation* is, strictly speaking, automatic in this sense (cf. Bach et al., 2007). Tipper, Paul, and Hayes (2006) recently reported similar results related to the activation of motor programs by the perception of object affordances.

Although automatic imitation is not immune to top-down influences, it is just as clearly not controlled, being generally unintentional and outside of conscious awareness. This highlights a more general problem with the traditional concept of automaticity in that very few—if any—processes can be neatly characterized as either automatic or controlled, though these designations were traditionally proposed to be mutually exclusive and exhaustive. Logan and Cowan (1984), for example, pointed out that typical examples of purportedly automatic processes such as reading, or driving, are in fact under robust cognitive control in that a person can easily decide to stop reading or driving at any time. Even more problematic, prototypically automatic processes, such as word reading in the Stroop paradigm, are highly susceptible to the direction of attention and task goals (Bargh, 1989; Carr, 1992).

Given that virtually no processes are entirely free from some type of control, an increasing number of authors are defining automaticity in terms of the level of processing at which control occurs rather than in terms of whether a process is controlled (it always is, to some extent). Neumann (1984), for example, argued that people should conceive of "automatic processing not as lacking control, but as being controlled at levels below the level of conscious awareness" (p. 256). Bargh (1989), similarly, wrote that "what all [automatic processes] seem to have in common is that they are autonomous, not requiring conscious control (at least to some extent) once they are initiated" (p. 38). Hommel (2000) argued that automatic and intentional processes should be thought of as occurring at different points in time, not as mutually exclusive. On this view, intentional and attentional weighting creates a certain task set; once that task set is instantiated, behaviors follow automatically from stimuli, in what Hommel (2000) termed a *prepared reflex*. The present results suggest that automatic imitation is consistent with this sort of prepared reflex; whether a particular stimulus will elicit automatic imitation depends on the task set of the participant (which can be manipulated by instructions), but once the task set is in place, imitation follows in a completely automatic fashion.

Automatic and Intentional Imitation

One implication of this research is that the findings show the importance of distinguishing between automatic and intentional imitation. In Experiment 3, participants were instructed to imitate the observed finger movement (i.e., intentional imitation) and responded as fast to impossible as to the possible movements. By contrast, participants responded faster to the anatomically compatible movements versus incompatible movements in Experiment 2 (i.e., automatic imitation) only when the movements were biomechanically possible. If intentional imitation relied on the same neural network as automatic imitation, then participants in Experiment 3 should have responded more quickly to possible than to impossible movements because the observation of the latter could not be completely matched to the motor response. Contrary to this prediction, participants responded as quickly when imitating impossible as opposed to possible movements. This discrepancy in the results is suggestive of fundamental differences between automatic and intentional forms of imitation, a distinction that has often been overlooked in the literature. One intriguing possibility is that although both goals and movements may mediate automatic imitation, goals may be of special importance in intentional imitation (cf. Bekkering, Wohlschläger, & Gattis, 2000; Wohlschläger et al., 2003).

Williamson and Markman (2006) argued that children (and perhaps adults) intentionally imitate observed actions conservatively (i.e., by replicating the precise movements) when the reason for the observed action is unclear, whereas they imitate the goal by the most convenient means when the reason for the goal is known. In the present study, the purpose of the observed finger movements was entirely ambiguous. Nevertheless, the default mode of automatic imitation was in terms of the goal, rather than the manner in which the action was performed. This again suggests a potential difference between automatic and intentional imitation.

As a final comment, we wish to point out that, along with the study of Longo (2006), the present data offer the first unequivocal evidence of automatic imitation of a computer-generated virtual hand. Perani et al. (2001), using positron emission tomography, found that only a video image of a real hand activated the human mirror system; neither a robot-arm stimulus nor a virtual hand was sufficient. Other studies have found similar results comparing actions produced by humans or by mechanical actors (e.g., Kilner, Paulignan, & Blakemore, 2003; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004). By contrast, Press et al. (2005) showed that the perception of actions performed by a robotic arm resulted in automatic imitation, though less than that elicited by a video image of a real arm. Similarly, the computer-generated virtual hand in the present study was clearly sufficient to elicit automatic imitation, at least when the movement was biomechanically possible. In contrast to the findings of Press and colleagues, the magnitude of the imitation effect observed in this study is comparable with that observed from a video of a real hand in our previous study (Bertenthal et al., 2006). One possible reason for this difference is that the virtual hand used in the current study was so realistic that participants may not have interpreted it as computer generated. It may be that if attention were drawn to the fact that the hand is computer generated, automatic imitation would be reduced or eliminated. Additional research is needed to address this issue.

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