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Journal Article

Running head: Imitation of Impossible Movements

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

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Abstract

Recent behavioral, neuroimaging, and neurophysiological research suggest a common representational code mediating the observation and execution of actions; yet, the nature of this representational code is not well understood. We address this question by investigating whether this observation-execution matching system (or mirror system) codes both the constituent movements of an action as well as its goal, and how such sensitivity is influenced by the top-down effects of instructions. Automatic imitation of observed finger actions was tested by manipulating whether the movements were biomechanically possible or impossible, while 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 the difference between possible and impossible movements (Experiment 2), only possible movements elicited automatic imitation. This sensitivity was specific to imitation, not affecting spatial S-R compatibility (Experiment 3). These results suggest that ~~the human mirror system is~~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

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

The ability to understand the actions and mental states of those around us is crucial for interacting effectively in our 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., ~~in press~~2007; Longo, 2006; Longo & Bertenthal, 2006~~, 2007~~; 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 et al. (2001), perceptual and motor events are coded in terms of a shared set of features. While 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. claim 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.

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 ~~had been~~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 ~~had been~~was described in terms of illuminating the light, this pattern reversed; the compatibility effect depended on the location of the light, rather than the location of the pressed button~~ being pressed~~. Thus, whether attention ~~had been~~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 which 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

~~have found~~report that simply describing the response-keys using horizontal (i.e., “right”/”left”) or vertical (i.e., “top”/”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” vs. “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 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. While 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 subjects 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 ~~being~~ 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 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 ~~have to~~ imitate the action as opposed to simply watch the action. Similarly, Zentgraf and colleagues (2005) told participants that after the study they would ~~have to~~ either imagine performing or evaluate the quality of observed gymnastics sequences, and 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 vs. movements.

Common Coding of Movements vs. 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) writes (p. 168):

> "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."

~~Numerous authors have pointed out t~~The ability of humans to imitate actions at multiple levels, either in terms of goals (or effects) or of movements (e.g., Koffka, 1924/1959; Miller & Dollard, 1941; Morgan, 1900; Stränger & Hommel, 1995), ~~which are~~is 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., for example, suggest 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 et al., 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 where participants were explicitly instructed to imitate what a model did. By contrast, it is not clear if 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, speculate 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 suggest 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, Mattaghy, 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 (MEPs) 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.

~~*Overview of the Present Stud*~~*Statement of the Problem*~~

The goal of the present study was to examine~~d~~ the role of attentional weighting in automatic imitation. In particular, we investigated how directing attention to the manner in which actions were performed ~~would~~ affects the relative influence of goals and movements in the common coding of perceived and produced actions. The basic logic was to present actions which 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, since 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 to 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 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.). 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 ~~spontaneous.ly~~spontaneously coded. Experiment 2 investigated the effects of attentional weighting on automatic imitation. Participants were explicitly told at the beginning of the experiment 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 the 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 paid for their participation. An additional five 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 five 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 ~~being~~ done correctly, participants ~~had~~

subsequently ~~spontaneously~~ 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 weren't 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 eight volunteers at University College London (4 female; 4 male) rated the stimuli, but did not complete the full paradigm.

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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 13.3º horizontally and 10º vertically, and was embedded in a blue rectangular region measuring approximately 20º x 13.3º. The displacement of the moving index and middle fingers was approximately 1.9º 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 was 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, the model was imported into 3D Studio Max (Autodesk, San Rafael, CA) and 22 bones from the upper shoulder to the tip of the fingers were added. 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).

*** INSERT FIGURE 1 ABOUT HERE ***

Ratings of the stimuli were obtained from ~~an additional~~ eight 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 seven-point Likert scale with a score of 3 indicating that the participant "strongly agreed" with the statement, a score of -3 that they "strongly disagreed", and a score of 0 that they "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 sec.

Results and Discussion

Two questions were addressed in this section. The first concerned 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 concerned whether automatic imitation would be elicited by both possible and impossible finger movements.

Stimuli Ratings. Stimuli were rated by the eight participants~~, none of whom~~ who did not participate~~d~~ in the main experiment. ~~The r~~Ratings of the stimuli are shown in Figure 2. Participants ~~who rated the stimuli~~ strongly agreed that the possible finger movements looked like an action they could perform themselves, 2.91, $t(7) = 44.19$, $p < .0001$; like an action that most people could perform, 2.91, $t(7) = 44.19$, $p < .0001$; and that the finger movement looked natural, 2.52, $t(7) = 9.25$, $p < .0001$. They strongly disagreed that the possible finger movement looked like something they couldn't do, -2.94, $t(7) = -71.79$, $p < .0001$; and that the finger looked

broken, -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, -2.09, $t(7) = -3.10$, $p < .02$; like an action most people could perform, -2.28, $t(7) = -6.06$, $p < .001$; and that the finger movement looked natural, -2.59, $t(7) = -13.75$, $p < .0001$. They strongly agreed, however, that the impossible finger movements looked like something they couldn't do, 2.03, $t(7) = 3.14$, $p < .02$; and that the finger looked broken, 2.41, $t(7) = 9.01$, $p < .0001$.

These ratings provide strong evidence that the manipulation of possible vs. 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 one 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.

*** INSERT FIGURE 2 ABOUT HERE ***

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, $F(1, 23) = 9.71$, $p < .01$, partial $\eta^2 = .297$ (see Figure 3); response times were faster to

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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 to possible (315.85 ms) and impossible (317.76) movements, $F(1, 23) = .67$, *n.s.*, partial $\eta^2 = .028$, and there was no significant interaction between movement and compatibility, $F(1, 23) = .04$, *n.s*, partial $\eta^2 = .002$. 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, $t(23) = .20$, *n.s.*

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

*** INSERT FIGURE 3 ABOUT HERE ***

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). 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 fMRI, these researchers found similar activation of premotor mirror system regions elicited from observation of biomechanically possible and impossible actions (Costantini et al.)~~,~~; while using TMS, they found similar cortio-spinal excitability elicited by the observation of possible and impossible finger movements

(Romani et al.). Although several studies have found that actions that are not in one's motor repertoire at all (e.g., ballet moves) ~~fail to~~ 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 th~~is firste~~ 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 that 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, while 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.

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 paid for their participation. An additional four participants were excluded from analyses, one due to an error rate exceeding 25%, two who claimed to be "double-jointed," and one 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 RT was faster than 200 ms or slower than 1,000 ms were excluded from analysis. The results revealed a significant compatibility effect, $F(1, 23) = 5.12$, $p < .05$, partial $\eta^2 = .182$ (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, $F(1, 23) = 7.75$, $p < .01$, partial $\eta^2 = .252$, -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), $t(23) = 3.92$, $p < .001$, ~~there was~~ no such effect was revealed in response to impossible finger movements (.93 ms), $t(23) = .30$, *n.s.*; this difference 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 to possible (311.63 ms), and impossible (311.08 ms) actions, $F(1, 23) = .11$, *n.s.*-, partial $\eta^2 = .005$.

Errors occurred on 2.25% of trials, and 1.43% of trials were excluded due to 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 ~~differ significantly~~interact with the difference between possible and impossible movements, $t(23) = .59$, *n.s.*

*** INSERT FIGURE 4 ABOUT HERE ***

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 (-.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 or not 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 ~~more common~~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, while 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 of coding 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 ~~may have~~ led these movements to become distracting on account of their novelty and strangeness. ~~On~~ If this interpretation was correct, ~~rather than being interpreted as impossible, these actions~~then the impossible movements may simply have been seen as weird~~,~~ or unusual, ~~which could~~ disrupting performance and leading to a ceiling effect that ~~masking~~ 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 ~~from~~in the impossible finger movements condition, rather than ~~its masking~~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, a third and final experiment was conducted.

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, Experiment 3 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 ~~E~~experiment ~~3~~, 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.

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 paid for their

participation. An additional four participants were excluded from analyses, one due to a computer error, one due to an error rate exceeding 25%, and two who claimed to be "double-jointed".

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~~y~~) 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 effect of compatibility, $F(1, 23) = 178.45$, $p < .0001$, partial $\eta^2 = .886$ (see Figure 5); responses were faster to spatially compatible (341.23 ms) than incompatible (380.63 ms) finger movements. ~~,~~ This indicates~~ing~~ that a spatial code shared between stimulus and response facilitated performance, consistent with our prior findings using the same paradigm (Bertenthal et al., 2006, Exp. 3a) ~~and~~ 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, $F(1, 23) = .09$, *n.s.*, partial $\eta^2 = .004$. Planned comparisons revealed ~~comparable~~ 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, $t(23) = .31$, *n.s.*

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*** INSERT FIGURE 5 ABOUT HERE ***

Unlike the first two ~~experimnts~~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, response times were similar for possible (360 ms) and impossible (361 ms) actions, $F(1, 23) = .34$, *n.s.*, partial $\eta^2 = .014$. This was true as well when compatible, $t(23) = .18$, *n.s.*, and incompatible, $t(23) = .34$, *n.s.*, trials were examined separately with planned comparisons. Thus, while 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 due to 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, $t(23) = .41$, *n.s.*

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.

General Discussion

The aim of this research was twofold: (1) to investigate the attentional weighting effects of instructions on automatic imitation, and (2) 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 ~~the~~ 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 ~~constitutive~~constituent movements. When the experimenter instructed participants at the beginning of the experiment that they would see both “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 which Hommel et al. (2001) term 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 (~~in press~~2007), who found that the degree of spatial attention to a body part affects the extent of automatic imitation elicited. Second, while 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. While

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 ~~similarily~~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; Costantini et al., 2005) 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. and Romani et al., in contrast, differ only in *how* the action in performed. Whereas it was obvious that different movements and actions were

involve-d in the two ballet dances, the difference between the possible and impossible movements used ~~I~~in the latter two experiments were much less noticeable. The results from the current experiment show that automatic imitation is either sensitive (Experiment 2) or insensitive (Experiment 1) to whether or not 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 (1) capacity-free and effortless, (2) stimulus driven, and (3) 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., in press). 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, point out that typical examples of purportedly automatic processes such as reading, or driving, are in fact under robust cognitive control in that we 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 or not a process is controlled (it always is, to some extent). Neumann (1984), for example, argues that we 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, writes that "[w]hat 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) argues 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 terms 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 vs. 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 ~~significant~~ fundamental differences between automatic and intentional forms of imitation, a distinction that has often been overlooked in the literature. One intriguing possibility is that while 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) argue 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 PET, 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 to 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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Footnotes

1) The term *goal* is sometimes equated with the term intention. In this paper 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) At least when attention was not overtly drawn to the artificiality of the virtual hand.
3) As these distributions appeared to be heavy-tailed, Yuen's (1974) *t*-test for trimmed means was used, with 20% trimming (see Wilcox, 2005).
4) As with the comparison between Experiments 1 and 2, this comparison used Yuen's (1974) *t*-test for trimmed means, with 20% trimming.

Figure Captions

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 ~~row~~ panel displays the impossible movements. Within each panel, the top row displays the finger movements compatible with the participants' responses; the bottom ~~panel~~ row displays the finger movement incompatible with the participants' responses.

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

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.

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.

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.

Figure 1

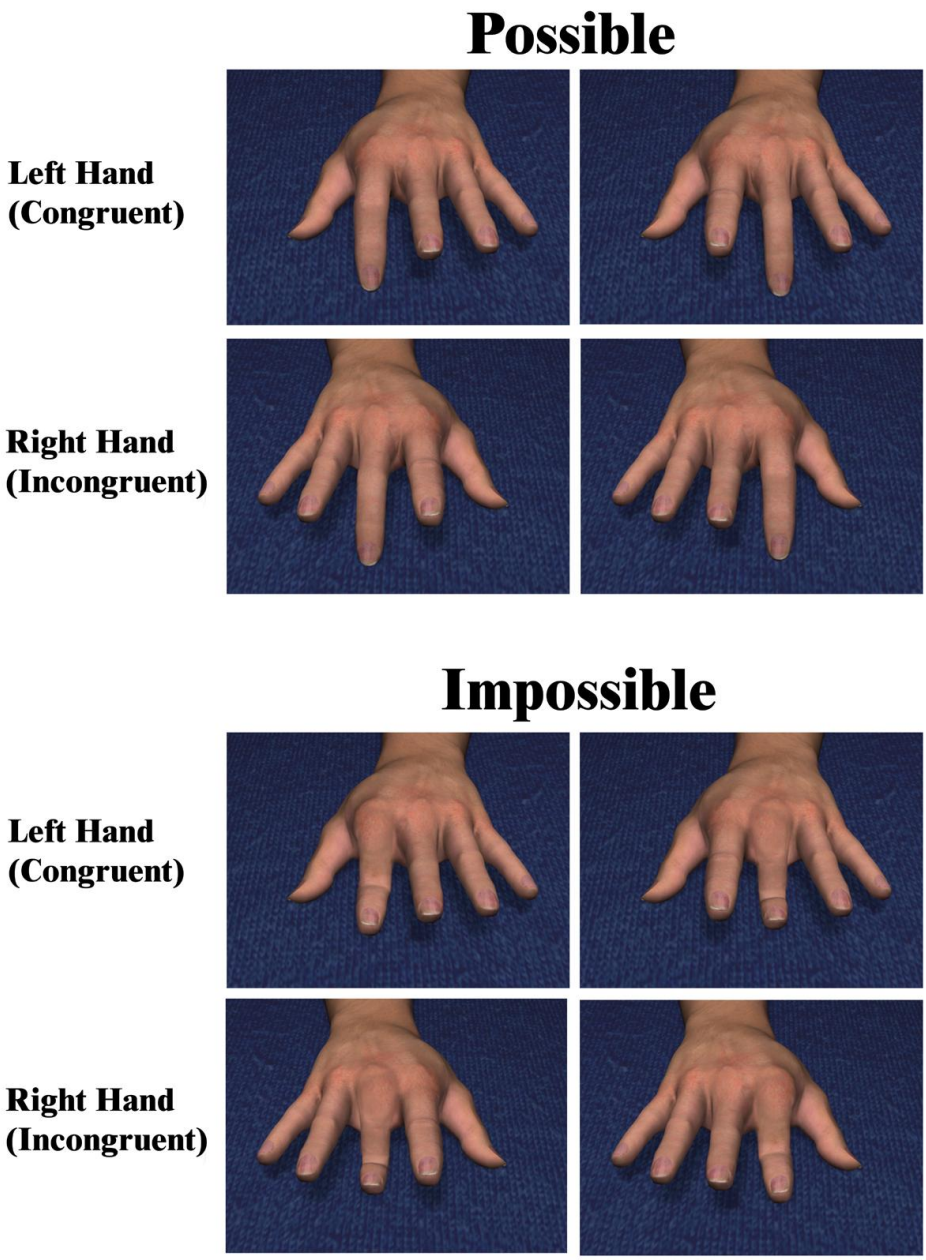

Possible
Left Hand
(Congruent)
Right Hand
(Incongruent)
Impossible
Left Hand
(Congruent)
Right Hand
(Incongruent)

Figure 2

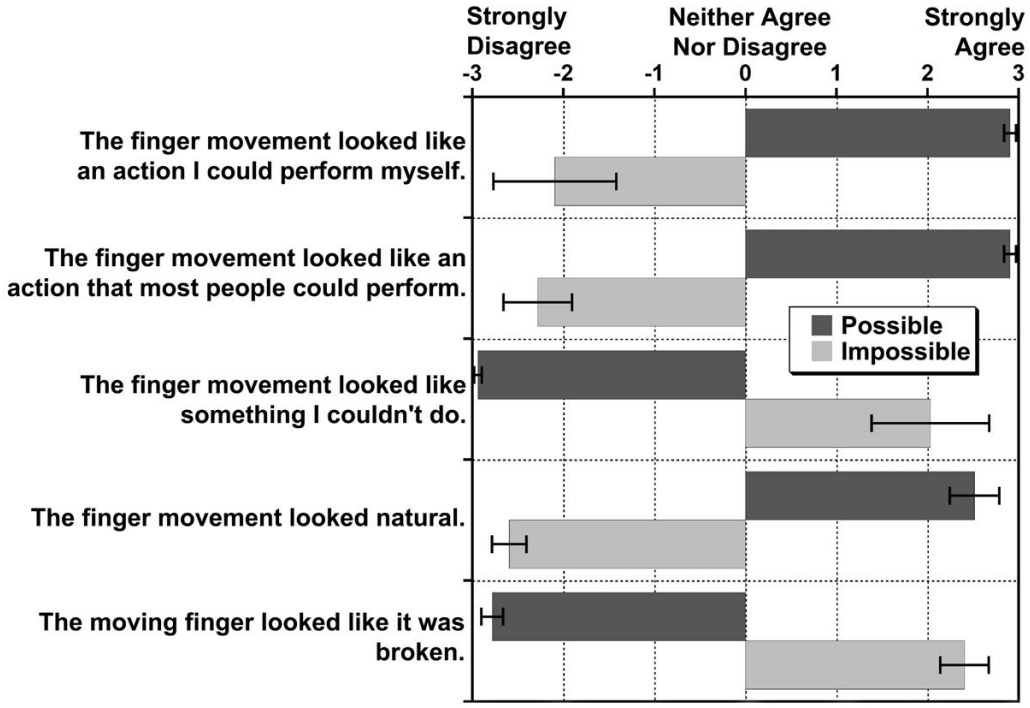

Strongly Disagree
Neither Agree Nor Disagree
Strongly Agree
-3
-2
-1
0
1
2
3
The finger movement looked like an action I could perform myself.
The finger movement looked like an action that most people could perform.
The finger movement looked like something I couldn't do.
The finger movement looked natural.
The moving finger looked like it was broken.
Possible
Impossible

Figure 3

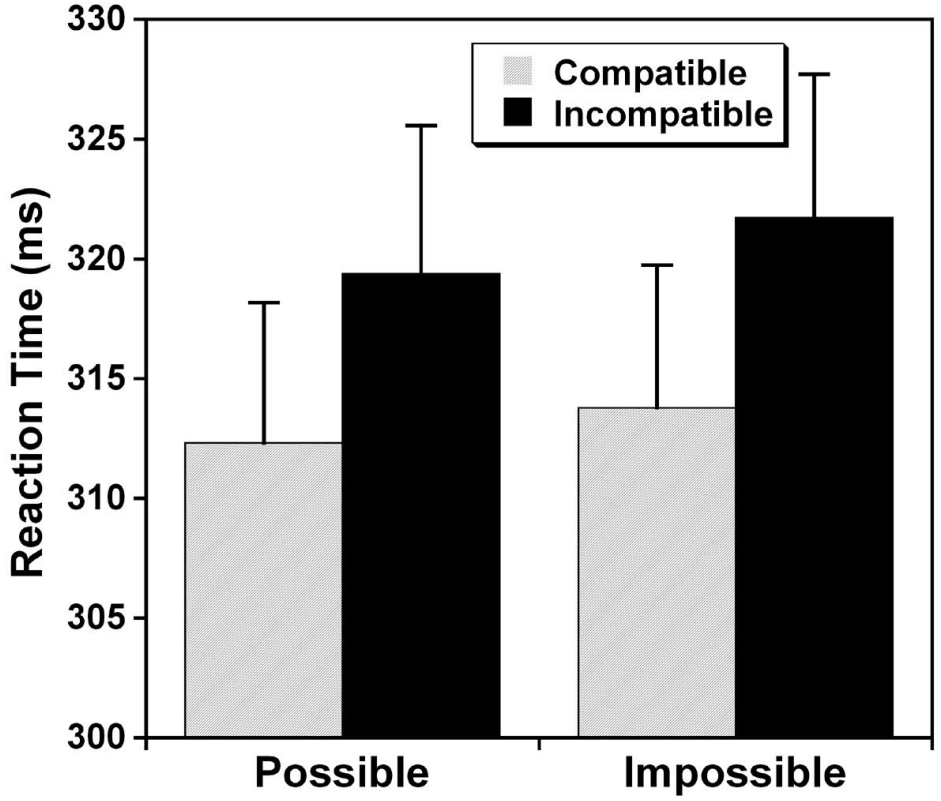

330
325
320
315
310
305
300
Reaction Time (ms)
Compatible
Incompatible
Possible
Impossible

Figure 4

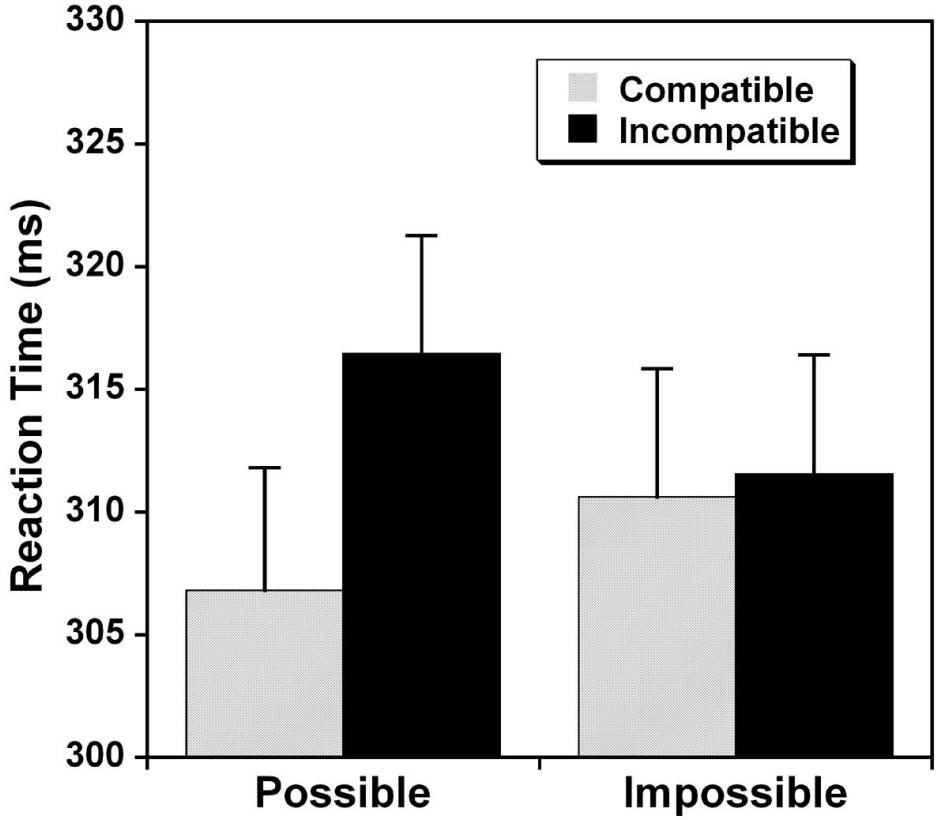
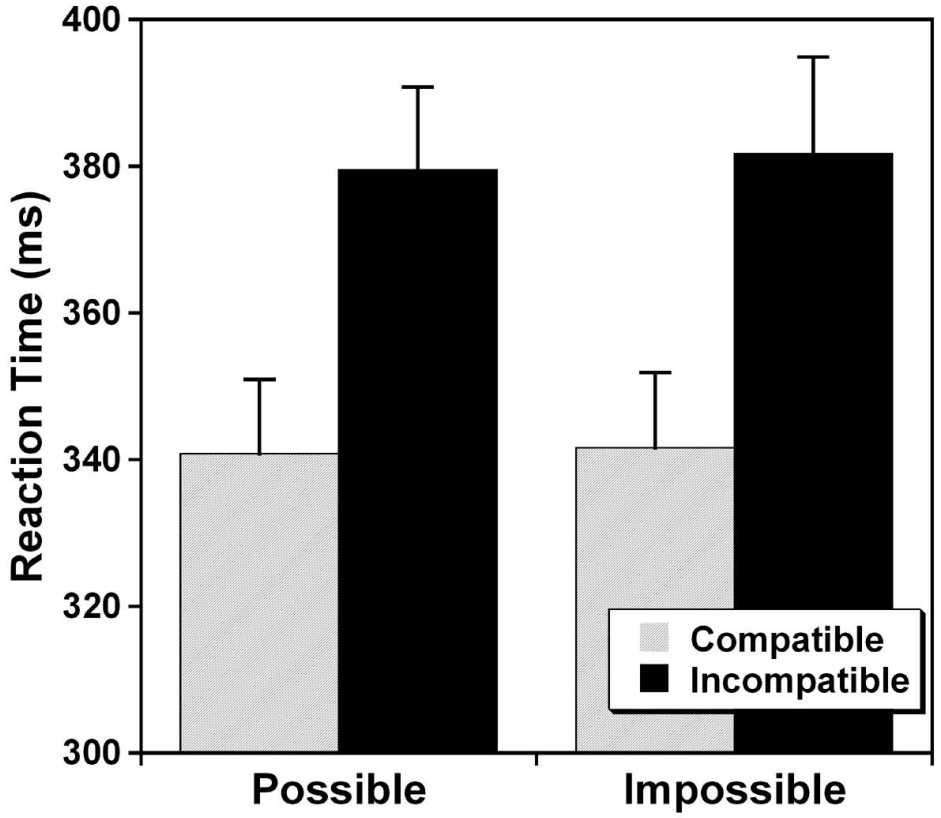

330
325
320
315
310
305
300
Reaction Time (ms)
Compatible
Incompatible
Possible
Impossible

Figure 5


400
380
360
340
320
300
Reaction Time (ms)
Compatible
Incompatible
Possible
Impossible