

A Functional Role for Motor Simulation in Identifying Tools

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Abstract

Embodied cognition promotes the involvement of the motor system in cognitive processing, such as tool identification. Although neuropsychological studies suggest that the motor system is not necessary for identifying tools, it may still have a functional role in tool recognition. To test this possibility, we used a motor interference task: Participants squeezed a rubber ball in one hand while naming pictures of tools and animals. Participants were faster and more accurate in naming the tools that were oriented with the handle facing away from the squeezing hand than in naming the tools that were oriented with the handle facing toward the squeezing hand. There was no effect of orientation for animals. Given that participants simulate grasping a tool with the hand closest to the handle, this result demonstrates that interfering with the ability to simulate grasping impairs tool naming and suggests that motor simulation has a functional role in tool identification.

Keywords

tool use, object identification, motor simulation, motor interference, embodied cognition

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Increasing evidence suggests that merely seeing objects that are typically manipulated in certain ways automatically triggers motor simulations for using them. For example, people are faster to make orientation judgments about a picture of a tool when the tool's handle is oriented toward the hand that will make a response than when it is oriented away from the responding hand. This finding suggests that the orientation of a tool evokes an action program for grasping it with the closest hand (Tucker & Ellis, 1998). Similarly, when reaching for a pencil, people have a larger grip aperture if a hammer is also present than if the pencil is by itself, which suggests that action programs for grasping different objects in peripersonal space are covertly triggered in parallel and interfere with each other (Castiello, 2005). Furthermore, neuroimaging studies indicate that cortical networks for hand action are engaged more by the sight of tools than by the sight of animals (see Lewis, 2006).

However, the extent to which motor simulations contribute functionally to tool recognition (as proposed by accounts of embodied cognition) remains unclear. Three possibilities exist: First, motor simulations may be necessary for tool recognition. Second, motor simulations may be supportive but not necessary for tool recognition. And finally, motor simulations may be connected to, but not functionally relevant for, tool recognition. Recent findings that bear on this issue come

from neuropsychological studies of patients with apraxia, an impairment of tool use that cannot be attributed to either low-level disturbances of motor control or high-level problems with task comprehension. Whereas some apraxic patients are impaired in both tool use and tool recognition, many are impaired in just tool use and have intact tool recognition. This suggests that motor simulations are not necessary for the latter task (Negri et al., 2007).

Nevertheless, motor simulation may still have a functional role in tool recognition. Motor interference impairs learning how to use functional objects (Paulus, Lindemann, & Bekkering, in press). Furthermore, motor simulation appears to play a causal role in several other types of cognitive processing, most notably in language comprehension. Facilitation of motor regions for the arms and legs (via transcranial magnetic stimulation) decreased participants' time to make judgments of action words related to the specific body part that was stimulated (Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005; but see Buccino et al., 2005, for another causal, though inhibitory,

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effect). Behavioral studies demonstrated that responding to sentences was faster when the response was compatible with the direction of movement implied in the sentence (Glenberg & Kaschack, 2002). Furthermore, after prolonged experience with one direction of movement, which leads to use-induced motor plasticity, sentence comprehension was slower for sentences describing that direction of movement than for sentences describing the opposite direction of movement (Glenberg, Sato, & Cattaneo, 2008). These studies point to a functional link between motor simulation and language comprehension.

Neuropsychological research in other domains has also demonstrated a functional role for motor simulation. Patients impaired at imitating mouth movements had more difficulty identifying sounds associated with mouth movements than in identifying sounds associated with hand movements, whereas patients impaired at imitating hand movements displayed the opposite pattern of difficulties (Pazzaglia, Pizzamiglio, Pes, & Aglioti, 2008). Cortical lesions in the motor system that impair movements with one arm but not the other also impair perceived biological motion of the hemiplegic arm but not the unaffected arm (Serino et al., 2010). Thus, there is also evidence for a causal link between motor simulation and processes such as visual and auditory action perception.

To investigate the possibility that motor simulation plays a functional role in tool recognition, we examined the impact of a motor interference task on tool naming. The simple presentation of a tool image may automatically evoke motor simulations of the actions associated with the tool, and specifically actions of the hand toward which the handle is oriented (Tucker & Ellis, 1998). Given that motor simulation shares many of the neurocognitive resources needed for motor execution (Grezes & Decety, 2001; Witt & Proffitt, 2008), we hypothesized that such motor simulations should be disrupted when subjects perform a simultaneous motor task, such as squeezing a ball, using the hand nearest the handle. Thus, if motor simulation plays a functional role in the conceptual processing of tools, motor interference from the hand that affords actions with a tool should slow latencies in naming the tool (Experiment 1) and reduce accuracy in naming the tool when its image is presented briefly (Experiment 2).

Experiment 1

Method

Sixty-three college students whose native language was English (30 female, 33 male; 59 right-handed) named colored photographs of tools and animals (control stimuli) presented on a white background. Instructions were to name each item as quickly as possible. Participants spoke into a microphone, and speech onset time was recorded. Errors were coded manually and removed from data analysis ($M < 0.06\%$). Each picture remained visible until named. A blank screen was presented for 1,500 ms between pictures. Objects were oriented with either the head of the animal or the handle of the tool to the left

or to the right. Participants completed two blocks, each containing all 48 tools and 50 animals. The orientation of a given object was the same in both blocks (e.g., if the handle of the hammer was on the right in the first block, it was also on the right in the second block). Object orientation was counterbalanced across participants. Object order within blocks was randomized. Participants squeezed and maintained constant pressure on a small foam ball with a different hand in each block. Hand order was counterbalanced across participants. Squeezing the ball engaged the motor areas necessary to simulate grasping, and thus should have interfered with simulation of grasping tools whose handles were oriented toward the squeezing hand. Instructions did not specify where the hands should be positioned, though participants typically placed their arms on the arm rests of the chair in which they were sitting.

Results

Participants were faster to name tools when the handle was oriented away from the hand squeezing the ball than when it was oriented toward that hand (see Fig. 1). A repeated measures analysis of variance (ANOVA) revealed a significant interaction between ball squeezing (i.e., the orientation of the tool's handle relative to the hand squeezing the ball) and stimulus type (tools vs. animals), $F(1, 62) = 6.35, p < .05, \eta_p^2 = .09$. There was also a main effect for stimulus type, $F(1, 62) = 217.37, p < .001, \eta_p^2 = .78$, though interpretations of this result should be tentative given that we did not equate pictures from the two categories. Rather, the same images were viewed with the left hand and the right hand squeezing the ball, and the key result is that there were differences in naming latencies depending on which hand was squeezing the ball. Separate repeated measures ANOVAs revealed a main effect of ball squeezing on naming latencies for tools, $F(1, 62) = 7.43, p < .01, \eta_p^2 = .11$, but not on naming latencies for animals, $F(1, 62) = 0.13, p > .71$.

Experiment 2

Method

Ninety-two participants (45 female, 47 male; 80 right-handed) participated in Experiment 2. The stimuli were the same as in Experiment 1. Each picture was displayed for a duration of 17, 33, 50, or 167 ms and then masked by a noise pattern. Picture-duration pairings were determined pseudorandomly such that there were equal numbers of trials of the two stimulus types (animal, tool) for each duration. Accuracy, rather than speed, was emphasized and recorded. Participants squeezed the ball in their right hand during one trial block and in their left hand during the other block. Hand order was counterbalanced across participants.

Results

Five participants were removed from analyses because their accuracy scores were statistical outliers in either the tool or the

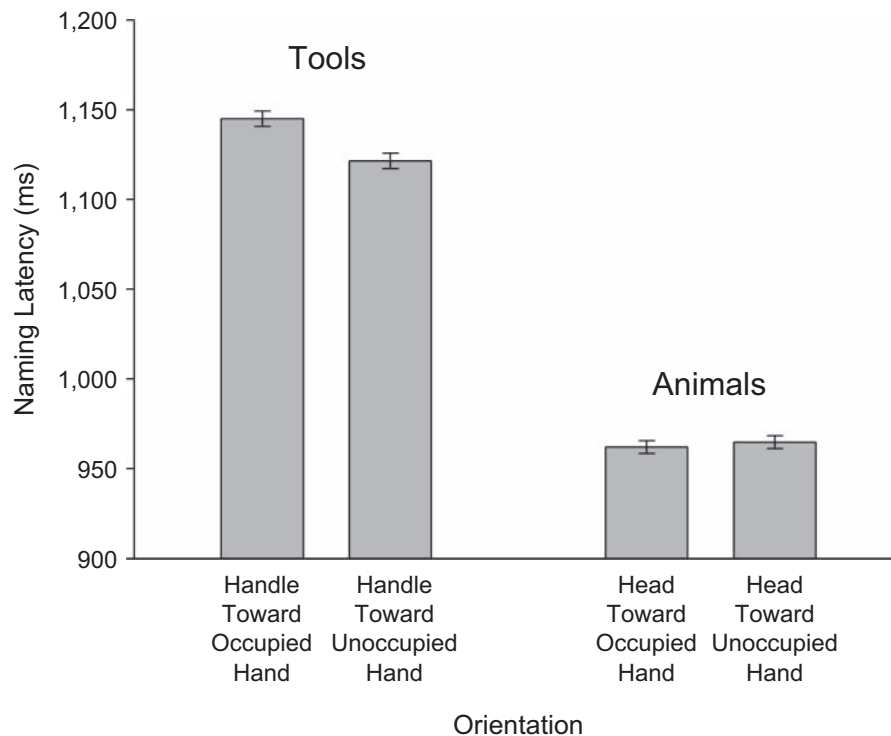


Fig. 1. Mean naming latencies for pictures of tools and animals, for trials on which the tool's handle or animal's head was oriented toward the hand that was squeezing the ball and trials on which the handle or head was oriented toward the hand that was not squeezing the ball. Error bars represent 1 SEM, calculated within subjects for each condition.

animal condition, as determined by a box plot. Participants named tools more accurately when the handle was oriented away from the hand squeezing the ball than when the handle was oriented toward that hand (see Fig. 2a). A repeated measures ANOVA on accuracy in naming the tool stimuli revealed a significant effect of ball squeezing, $F(1, 85) = 4.37, p < .05, \eta_p^2 = .05$. The main effect of duration was also significant, $p < .001$. The interaction of ball squeezing and duration was not significant, $F(3, 255) = 0.36, p = .78$. The lack of an interaction suggests that being able to grasp the handle with the nearest hand had an effect on naming the tools even when they were presented briefly (see Fig. 2b). In contrast, a repeated measures ANOVA on accuracy in naming the animal stimuli revealed no main effect for ball squeezing, $F(1, 85) = 0.13, p = .72$ (see Fig. 2a), and no interaction between ball squeezing and duration, $F(3, 255) = 0.13, p = .94$.

General Discussion

How can simply squeezing a ball slow down and reduce accuracy in naming tools? We propose that the reason has to do with motor simulation. Seeing a tool automatically evokes a motor simulation of acting on the tool with the hand closest to the handle (Tucker & Ellis, 1998). However, squeezing a ball with this hand engages the same processes as would be necessary to simulate grasping the tool, thus interfering with the simulation (Witt & Proffitt, 2008). If motor simulation played

no causal role in conceptual processing of tools, participants would have been equally fast and accurate in naming the tools regardless of which hand held the ball. However, participants were slower (Experiment 1) and less accurate (Experiment 2) in naming the tool when the ball was in the hand that was on the same side as the tool's handle, presumably because squeezing the ball interfered with the motor simulation of grasping the tool with that hand.

In contrast, squeezing the ball had no effect on speed or accuracy when participants named animals. Processing animals does not recruit motor knowledge, as evidenced by the lack of activation in motor-related areas (see Lewis, 2006). Thus, interfering with motor simulation via ball squeezing did not affect performance in naming animals. The fact that ball squeezing had an impact on naming tools but not animals implies that these effects are specific to motor processing, rather than being due to the relative location of visually salient features (Cho & Proctor, in press).

Given the possibilities outlined in the introduction, our results support the second possibility—that motor simulation plays a functional, but not necessary, role in tool recognition. In contrast, naming animals does not recruit motor knowledge and thus was unaffected by squeezing the ball. Motor interference is restricted to objects that elicit specific motor programs. In conclusion, these two experiments show that conceptual processing of action-related objects benefits from motor simulation of acting on the objects, demonstrating a functional

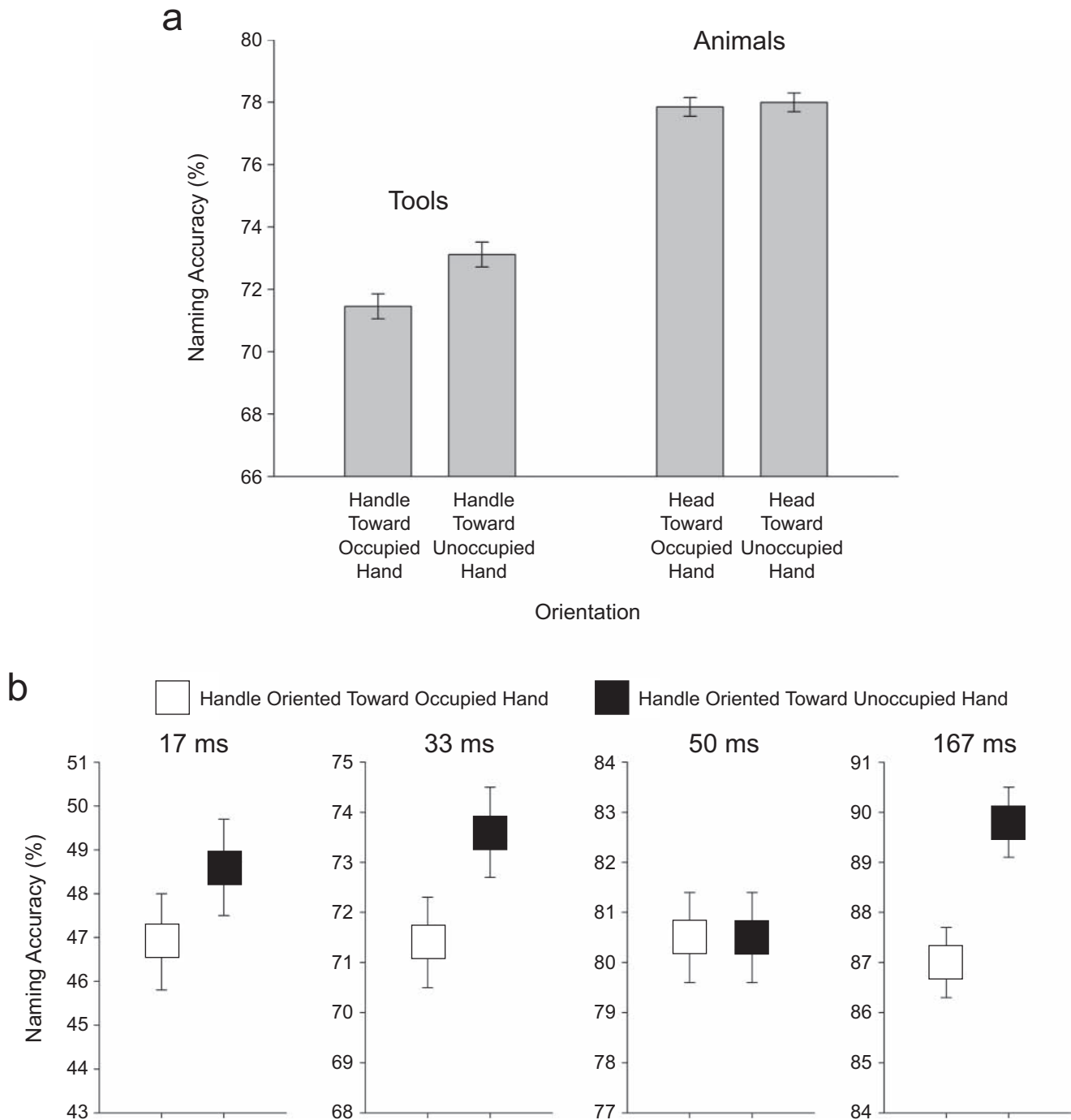


Fig. 2. Results from Experiment 2: mean naming accuracy for pictures of tools and animals for trials on which the tool's handle or animal's head was oriented toward the hand that was squeezing the ball and trials on which the handle or head was oriented toward the hand that was not squeezing the ball. The graph in (a) shows results for the four presentation durations combined, and the graphs in (b) show results separately for each presentation duration. Error bars represent 1 SEM , calculated within subjects for each condition.

rather than correlational link between motor and conceptual knowledge.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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