

Interaction between affordance and handedness recognition: a chronometric study

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Abstract

The visualization of tools and manipulable objects activates motor-related areas in the cortex, facilitating possible actions toward them. This pattern of activity may underlie the phenomenon of object affordance. Some cortical motor neurons are also covertly activated during the recognition of body parts such as hands. One hypothesis is that different subpopulations of motor neurons in the frontal cortex are activated in each motor program; for example, canonical neurons in the premotor cortex are responsible for the affordance of visual objects, while mirror neurons support motor imagery triggered during handedness recognition. However, the question remains whether these subpopulations work independently. This hypothesis can be tested with a manual reaction time (MRT) task with a priming paradigm to evaluate whether the view of a manipulable object interferes with the motor imagery of the subject's hand. The MRT provides a measure of the course of information processing in the brain and allows indirect evaluation of cognitive processes. Our results suggest that canonical and mirror neurons work together to create a motor plan involving hand movements to facilitate successful object manipulation.

Key words: Affordance; Handedness recognition; Manual reaction time; Motor imagery; Mirror neurons

Introduction

Our knowledge about the world and how we interact with it are constrained by the way our bodies are built. It is necessary to deal with the inherent complexity of one's environment, given the computational limits of the human brain. Motor action occurs during explicit movement, but also when it is simulated using motor imagery (1). Motor imagery engages the same cortical ensembles that generate explicit motor output (2-7). Motor representations contribute to the identification of body parts (8-11), object affordances (12,13,) and the recognition of actions performed by another individual (1,14,15).

Some studies have shown that the visualization of tools and manipulable objects activates motor-related cortical areas (12,13,15-17) to facilitate possible actions toward them (17-19). Gibson (20) called this phenomenon affordance, which can be described as how the design aspect of an object suggests how it should be used (21). That is, the visualization of an object should elicit subthreshold activation of motor systems involved in behaviors associated with the object.

A correlate of this subthreshold activation of motor programs can be observed during a handedness recognition

task (8-10,22,23). According to Parsons (8), judging the handedness of a visually presented hand stimulus involves a pre-attentive handedness-recognition process followed by a mental simulation of one's own hand moving toward the stimulus. Motor imagery of body segments follows rules similar to those involved with the mental representation of inanimate objects. A crucial difference, however, is that the motor imagery of body segments incorporates the biomechanical constraints of the real structures (8,9).

Early works demonstrated that previous visualization of stimuli representing the human hand in either static or dynamic grasping postures interacted with motor programs afforded by visual objects and shortened the time necessary for their categorization (13,24,25). Craighero et al. (26) demonstrated that the initiation of a grasping action could be modulated by priming postures that did or did not match the planned effector and its orientation. These early studies employed mental chronometry to infer the cognitive processes associated with the experimental tasks (13,24-26). More specifically, manual reaction time (MRT) measurements are capable of uncovering the

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temporal characteristics of motor programs triggered by the visualization of the hands and objects (13,24-26).

Action simulation driven by the visualization of hand postures could be supported by the “mirror neuron system” (27). On the other hand, the motor programs associated with how to grasp objects are supposed to be implemented by canonical neurons (28). Brain imaging and neurophysiological experiments have shown that both mirror and canonical neurons exist not only in monkeys but also in humans (27,28).

In the present study, we employed a priming paradigm in which a graspable visual object was the priming stimulus and a drawing of a human hand was the target (or imperative) stimulus; both stimuli were used in a single handedness recognition task. The MRT associated with laterality choices by the subject was the dependent variable, and the spatial correspondence between the side of the object's handle and the side of hand and the congruency between the orientation of the object's handle and the subject's hand were used as independent variables. This arrangement enabled us to evaluate whether the affordance of the object would interact with the motor imagery needed to recognize the laterality of the picture of a human hand. If our hypothesis is correct, the visualization of an object and the subsequent subthreshold activation of motor programs associated with its manipulation will interfere with the motor programs implicitly activated by handedness recognition.

Material and Methods

Participants

Sixteen volunteers (9 males, 18-30 years old, mean age = 26.5 years) participated in this experiment. All volunteers were undergraduate biology students at the Universidade Federal Fluminense. All were right-handed (29), had normal visual acuity, and were unaware of the purpose of the experiment. Written informed consent was obtained from all subjects, and the study was approved by the research ethics committee of the Universidade Federal Fluminense (#185/2005).

Procedure

Digital photographs of either a door handle (left or right) or a kettle (left or right handle) were selected as visual primes. Four drawings of the human hand were used as targets (Figure 1). Drawings were viewed from the wrist perspective in two orientations (0° palm down and 90° thumb upward) and were randomly presented. The left and right hands were identical mirror images of each other. The stimuli were about 15.5° tall and 9.3° wide in the thumb upward orientation and 9.3° tall and 15.5° wide in the palm down orientation and had a black outline against a white background (see Figure 1). The experiment was conducted in a quiet, dimly lit room. A desktop computer was used for both stimulus presentation

and recording the subject's responses. The participants were positioned in an adjustable forehead-and-chin rest so that the distance between the eyes and the screen was about 57 cm. The Micro Experimental Laboratory (MEL, version 2.0) software was used to manage the experiment and measure response latency. The stimuli were displayed on a 20-inch VGA monitor and were presented at the center of the screen. The responses were performed using the index fingers by pressing one of two switches located about 25 cm to the left and right of the participants' midline. Throughout the test, the right index finger pressed the right response key and the left index finger pressed the left key response.

Each trial started with the appearance of an object at the center of the screen (door handle or kettle) for 1500 ms. The priming stimulus then disappeared, and after 1000 ms, the drawing of the left or the right hand appeared in one of the two orientations (0° palm down/90° thumb upward). The drawing remained on the screen for 1000 ms and the subjects responded by pressing one of the two micro-switches. The task was to press the right key with the right index finger for the right-hand drawing and the left key with the left index finger for the left-hand drawing.

Subjects participated in a single session subdivided into 2 blocks of 88 trials, for a total of 176 trials per session. Subjects were instructed to simply observe the priming object and to respond as quickly as possible to the subsequent hand drawing by pressing either the right or left micro-switch.

Analysis

The average of correct MRTs was entered into an analysis of variance (ANOVA) with the following factors: correspondence (correspondent/noncorrespondent), match (match/non-match), and orientation (0° palm down/90° thumb upward). Correspondence was defined as the correspondence between the hand afforded by the visual object (affordance to the right or left hand) and the handedness of the drawing (right or left hand). For instance, a correspondent trial occurred when the priming object was a picture of a kettle with the handle pointing to the right and the target was the drawing of a right hand (see Figure 1). Match was defined as the congruence between the object (door handle or kettle) and the orientation of the hand drawing (0° palm down/90° thumb upward). A matching trial occurred when the priming object was a kettle and the target was a drawing representing a hand oriented in a posture adequate to grasp it (90°: thumb upward; see Figure 1). The criterion for statistical significance was set at $\alpha = 0.05$.

Results

ANOVA showed that all three factors were significant in modulating MRTs: correspondence ($F[1,15] = 6.01$;

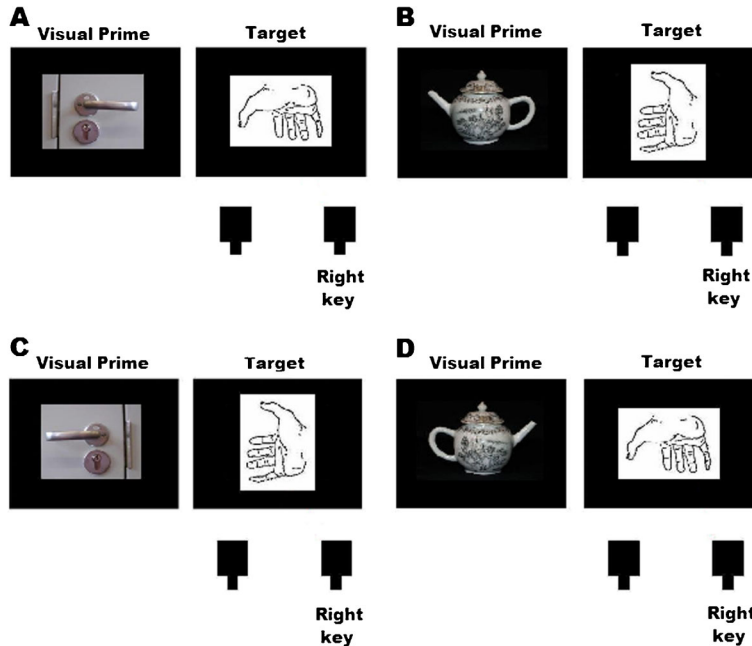


Figure 1. Experimental setup: *A* and *B* show a correspondent and matching conditions, respectively. In both, the action afforded by the visual object is right handed, while the target is a drawing of the right hand in the afforded posture. *C* and *D* show non-correspondent and non-matching conditions, respectively.

$P < 0.026$), match ($F[1,15] = 5.94$; $P < 0.027$), and orientation ($F[1,15] = 47.30$; $P < 0.001$). The average MRTs to the correspondent conditions (561 ± 2.24 ms) were 12 ms faster than to the non-correspondent conditions (573 ± 2.37 ms, $P < 0.026$). For example, when the object afforded a grasp with the right hand and the target was a drawing of the right hand, the MRT to the correct response was 12 ms faster than when the object afforded a grasp with the left hand and vice versa. The average MRTs to the matching conditions (562 ± 2.23 ms, $P < 0.027$) were 10 ms faster than to the non-matching condition (572 ± 2.38 ms). Thus, the MRT was 10 ms faster when the hand drawing was oriented in a posture adequate to grasp the priming object. The influence of biomechanical constraints on motor imagery was revealed by the faster MRTs when the hand stimulus was in thumb upward orientation (531 ± 2.27 ms) compared to a palm down orientation (603 ± 2.61 ms). There was no interaction between the factors.

Discussion

The ideal result of evolutionary adaptation is to make the animal and its environment “mutually compatible” (20). Our main goal in the present work was to provide evidence for this “mutual” relationship using a mental chronometry strategy implemented in a handedness discrimination task.

Our results showing that latency for handedness recognition varies according to hand orientation (0° palm down/ 90° thumb upward) were similar to those described

by Parsons (8,9), indicating that hand movements that requires less effort to be executed or mentally represented were faster than those requiring greater effort. Moreover, according to Parsons (8), judging the handedness of a visually presented hand stimulus involves a pre-attentive handedness-recognition process followed by a mental simulation of one’s own hand moving towards the stimulus, which may be related to mirror neuron activation (11).

Our findings showed that handedness recognition is faster when associated motor imagery is primed by a correspondent affordance. The visualization of manipulable objects (door handle or kettle) activates an affordance to a specific hand (right or left hand) and a specific posture to grasp it. This result suggests that the same motor programs are activated for different processes including handedness recognition (8,9,10,17) and the recognition of actions performed by another individual (14,15).

Experiments in monkeys show that neurons in the premotor cortex code a “vocabulary” of potential motor actions. These neurons can be activated endogenously or following presentation of specific stimuli (27,28,30), such as objects (object-related activation) or the motor behavior of another individual (action-related activation). The ventral premotor area F5, for instance, possesses three main classes of neurons: motor, canonical, and mirror. The activities of canonical and mirror neurons are not necessarily associated with overt motor output. Rather, canonical neurons respond to the visualization of manipulable objects (object-related activation) and during the performance of a meaningful motor action toward those objects (17,31,32). Conversely, mirror neurons discharge

when the monkey performs an action or observes another individual performing the same action (action-related activation) (14,27,31,33).

Several studies have been carried out to identify human correlates to these groups of neurons found in monkeys (15,33-35). Some studies have pointed to Broca's area as the human homolog of the monkey's premotor area F5 (15,32,35,36). Grèzes et al. (37), using event-related functional magnetic resonance imaging to show that the ventral portion of the precentral sulcus in the human brain may have functions similar to area F5 in the monkey.

Canonical neuron activity in the premotor cortex could encode the action representation afforded by visual objects (16,17,37,38). Mirror neurons, on the other hand, could represent action involved with motor imagery during handedness recognition (11,24). For instance, cortical regions activated during body part recognition overlap with anatomical areas within the mirror neuron system (8-10).

When prompted to determine the handedness of a visual stimulus (figure of a hand), the subject relies on both external (visual) and internal (proprioceptive) cues. The visualization of the stimulus sets off a chain of events that culminates with

the subject simulating, through motor imagery, his own hand projecting toward the stimulus on the screen and verifying their congruence (8,9). This simulation depends on the initial state configuration of the subject's hand, which is informed by proprioceptive inputs (8,9).

In the present study, the MRT for handedness recognition was primed by the affordance of a previously shown manipulable object. Our results suggest that both canonical and mirror neurons work together to generate motor representations that are appropriate for successful object manipulation (39), facilitating the acquisition of new motor skills and tool use.

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