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Viewing objects and planning actions: On the potentiation of grasping behaviours by visual objects

Stergios Makris *, Aviad A. Hadar, Kielan Yarrow

Department of Psychology, City University, London, United Kingdom

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ABSTRACT

How do humans interact with tools? Gibson (1979) suggested that humans perceive directly what tools afford in terms of meaningful actions. This "affordances" hypothesis implies that visual objects can potentiate motor responses even in the absence of an intention to act. Here we explore the temporal evolution of motor plans afforded by common objects. We presented objects that have a strong significance for action (pinching and grasping) and objects with no such significance. Two experimental tasks involved participants viewing objects presented on a computer screen. For the first task, they were instructed to respond rapidly to changes in background colour by using an apparatus mimicking precision and power grip responses. For the second task, they received stimulation of their primary motor cortex using transcranial magnetic stimulation (TMS) while passively viewing the objects. Muscular responses (motor evoked potentials: MEPs) were recorded from two intrinsic hand muscles (associated with either a precision or power grip). The data showed an interaction between type of response (or muscle) and type of object, with both reaction time and MEP measures implying the generation of a congruent motor plan in the period immediately after object presentation. The results provide further support for the notion that the physical properties of objects automatically activate specific motor codes, but also demonstrate that this influence is rapid and relatively short lived.

1. Introduction

What is the linkage between perception and action? Gibson's (1979) ecological approach to perception suggests that people not only perceive the physical properties of an object or tool, but also what they can do with it. Hence objects have meanings in terms of the observer's repertoire of actions. These meanings are perceived by the user upon first-sight of an object, with minimal intervening cognitive operations. This is the theory of "affordances". Gibson (1979) described affordances as the functional characteristics of an object and the possible actions it could afford based on the motor capabilities of a person.

The concept of the affordance has proved compelling to many researchers, and has recently been incorporated in an influential theory of motor decision making known as the affordance competition hypothesis (Cisek, 2006, 2007). Cisek suggests that multiple motor plans are generated automatically across visuo-motor regions of the cortex in response to attended stimuli. Mutual inhibitory connections between motor plans, and biasing inputs from decision centres, drive changes in neural activity which determines a single winning motor act.

Theories of this kind suggest that the viewing of an object potentiates a motor plan even when there is no intention to implement it. Such a strategy might at first glance appear wasteful, because many plans would be formulated for acts that were never subsequently performed. However, the existence of motor plans to deal with a multitude of contingencies might provide a crucial speed advantage (Yarrow, Brown, & Krakauer, 2009). Findings from the fields of experimental psychology and neuroscience have demonstrated that the simple viewing of an object can indeed stimulate the human motor cortex into producing plans for action (e.g. Chao & Martin, 2000; Craighero, Fadiga, Rizzolatti, & Umiltà, 1999; Tucker & Ellis, 1998, 2001).

In a seminal study, Tucker and Ellis (1998) demonstrated that the handle orientation of a common object such as a saucepan, though irrelevant to the task, influenced the participants to give faster responses when response hand and orientation of the handle were matched. In subsequent work, they had participants view objects that would usually be picked up either by pinching or grasping. At the same time, participants responded to auditory stimuli, using an apparatus that mimicked a precision or a power grip. The results showed a significant interaction between type of response and the visually-afforded object grip (Ellis & Tucker, 2000). Hence results from both studies are consistent with the idea that the objects

* Corresponding author. Address: Social Science Building, City University, Northampton Square, London EC1V 0HB, United Kingdom. Fax: +44 (0)20 7040 8580.

E-mail address: stergios.makris.1@city.ac.uk (S. Makris).

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had automatically generated compatible motor plans, giving a reaction-time advantage to the congruent motor response. Further studies in the field have supported the notion of objects directly eliciting action patterns independent of the intentions of the person, both in cases of normal participants (e.g. Craighero, Fadiga, Umiltà, & Rizzolatti, 1996; Craighero et al., 1999; Phillips & Ward, 2002; Vingerhoets, Vandamme, & Vercammen, 2009) and neurological patients (Humphreys, Riddoch, Forti, & Ackroyd, 2004; Riddoch, Humphreys, Edwards, Baker, & Willson, 2003).

Evidence for affordances is not limited to behavioural studies. A study by Buccino, Sato, Cattaneo, Rodà, and Riggio (2009) applied a transcranial magnetic stimulation (TMS) protocol during which right-handed participants viewed pictures of familiar objects. Objects were oriented to the left or the right, and presented with either a whole or a broken handle. Very soon (200 ms) after first viewing the objects, participants received TMS over the left hemisphere hand motor area. The results showed that motor evoked potentials (MEPs) in the right hand were bigger when participants were presented with whole-handle objects oriented to the right, compared to all other experimental conditions. The sizes of the MEPs recorded from a specific muscle are known to vary with increasing cortical preparation for relevant motor acts (Izumi et al., 1995; Rösler & Magistris, 2008) so this finding can be taken to imply that a right-handed action was being planned to a greater extent in response to right-oriented objects.

These data are in agreement with findings from several neurophysiological and neuroimaging studies. In an early study Rizzolatti et al. (1988) tested the functional properties of motor neurons in macaque monkeys. Their findings suggested that the different types of motor neurons form a universal system of motor actions, and that this system is always accessed by visual stimuli. Further investigations have shown that the viewing of common objects can activate specific neural networks. In many cases the activation appears to happen spontaneously without a specific intention for action, and it is identified over brain regions that are related to motor behaviours. Grafton, Fadiga, Arbib, and Rizzolatti (1997) for example have found that the viewing of certain objects triggers a region located in the left dorsal premotor cortex, an area strongly associated with the potentiation of specific motor plans (see also Chao & Martin, 2000). Moreover, an fMRI study examining the findings of the Tucker and Ellis experiments confirmed a strong correlation between the size of the "affordances effect" and neural activity in parieto-frontal brain areas (Grèzes, Tucker, Armony, Ellis, & Passingham, 2003). More recently a neuroimaging study by Valyear, Cavina-Pratesi, Stiglick, and Culham (2007), looking at affordances shaped from viewing familiar tools, has shown a strong correlation between neural activity in intraparietal regions and grasp-related behaviours.

Here, we made use of the behavioural methods of Ellis and Tucker (2000) and the TMS approach of Buccino et al. (2009) in order to examine further how action-related information derived from visual objects automatically generates specific motor response codes for hand actions. More specifically, we presented incidental stimuli (pictures of objects) that have either strong significance for the actions of pinching and grasping or no such hand action significance. Meanwhile, subjects made power or pinch grip responses to an orthogonal visual stimulus (i.e. one that has no such prior association with the required responses; Experiment 1) or passively observed the objects while receiving TMS (Experiment 2). Thus far, little attention has been paid to the time course with which affordance-related motor activity develops, with a few studies suggesting that the affordances facilitation effect is long-lasting and gradually developing (Phillips & Ward, 2002; Vingerhoets et al., 2009). We therefore used different timings of stimulus presentation and target responses in an effort to yield a time course for the affordances effect.

In a first experiment, we applied a variant of the experimental paradigm described in Ellis and Tucker's (2000) research. In that study, participants were asked to respond by mimicking a precision or power grip to an orthogonal stimulus (an auditory tone) while real objects that should afford either precision or power grips were presented. To further develop the findings described by Ellis and Tucker (2000), an extra category of neutral objects was added to the stimulus set, while three different stimulus-onset asynchronies (SOAs) between the onset of the object image and the presentation of an orthogonal imperative stimulus were introduced to provide a time course for the phenomenon. If the affordances theory stands, a significant interaction between type of response and object type was expected to be found for objects with action significance.

In a second experiment a single-pulse TMS technique was employed. Participants observed the same pictures used in Experiment 1 while receiving magnetic stimulation over their dominant hemisphere hand motor area. Previously, Buccino et al. (2009) used TMS in a variant of Tucker and Ellis' original (1998) design: Responses were made with the right hand to stimuli with handles that could be oriented to either the left or right. This approach has been criticised by Anderson, Yamagishi, and Karavia (2002) who showed that even non-tool objects could interact with the hand used to make speeded responses when those objects had a clear left/right visual bias, perhaps because such objects give rise to shifts of attention that interact with lateralised motor planning. Buccino et al. attempted to control for this issue by including objects with broken handles, as well as lateralised abstract stimuli. Our experiment instead employed stimuli without any attention-directing cues that might prime a broad class of lateralised movements. Following on from our first experiment, and unlike the previously-described study by Buccino et al. (2009), three different times of stimulation were tested. Furthermore, in our experiment motor evoked potentials were recorded from two intrinsic hand muscles associated with either a precision or power grip. Our design thus discriminates between two closely-related movement plans generated within the same hemisphere of the brain, and demonstrates such affordances in the total absence of any requirement to act. If previous theories about cortical excitability over the primary motor areas and their connection to affordance-related activity of the premotor-parietal regions stand, our measurements for the effect of action-significant objects are expected to demonstrate a significant interaction between the type of object and the recorded hand muscle.

2. Experiment 1

2.1. Methods

2.1.1. Participants

The study was approved by the City University London Psychology Department Ethical Committee and was carried out in accordance with the ethical standards of the Declaration of Helsinki (1964). The study's sample consisted of 18 participants (16 females; Mean age = 21.5, SD = 3.7). Prior to starting the experiment they were all assessed by the Edinburgh Handedness Inventory (Oldfield, 1971); 17 were right-handed (Mean Lateralization index) (Li = 0.91, SD = 0.12), and one was left-handed (Li = −0.61). All participants reported normal or corrected to normal vision and were naïve to the purpose of the study. Informed consent was obtained from all participants and they were all compensated for taking part.

2.1.2. Material/apparatus

The stimulus set consisted of 45 objects; 15 objects associated with a power grip, 15 objects associated with a precision grip