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Are visual stimuli sufficient to evoke motor information?

Studies with hand primes

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Abstract

In two experiments we assessed whether seeing objects automatically activates information regarding how to manipulate them. In Experiment 1 participants categorized photographs of objects that could be manipulated either with a power or a precision grip into artefacts or natural kinds. Target-objects were preceded by primes consisting of photographs of hands in grasping postures (precision or power grip). Experiment 2 involved a preliminary motor training phase in which each visual prime was associated with the actual motor action. In both experiments, natural kinds graspable with a power grip produced the fastest responses. In Experiment 2 we also found a congruency effect between the prime and the kind of grip required by the object (precision, power). Results suggest that visual stimuli automatically activate motor information. Specific motor programs are, however, activated only if motor training is performed before the categorization task. Implications of the results for the understanding of the organization of conceptual and motor information in the brain are discussed.

INTRODUCTION

A recent account of conceptual knowledge (the Information Distributed Over Modalities Account, IDOMA; [3]) suggests that information is distributed over modality attribute domains (visual, tactile, etc.). These domains are more or less activated depending on their relevance during knowledge acquisition ([1]; [27]). According to this view, which is different from the classic information processing view, perception and action are not seen as functionally distinguishable stages, but as intimately related processes. In line with this account, various evidence on cortical object representation has shown that tools and manipulable objects, unlike non-manipulable artefacts, activate motor-related areas ([8]; [17]; [20]; [23]; [25]).

Consistent with the IDOMA theory, neuropsychological and behavioral studies confirm the tight interrelation between vision and action (e.g., [7]; [10]; [11]). Behavioral evidence with visuomotor priming and with compatibility paradigms (i.e. paradigms implying some kind of dimensional overlap between stimuli and responses) has shown that seeing an object re-activates previous action experiences with it. For example, Craighero *et al.* [9] instructed participants to prepare to grasp a bar, which could be oriented either clockwise or counter-clockwise, and to grasp it as fast as possible on presentation of a cue (the picture of a hand) (see also [33]). RTs were faster in cases of congruency between the hand position and the response position (the grasping hand final position). Tucker and Ellis [32] instructed participants to press a switch while mimicking a precision or a power grip to indicate whether objects were natural kinds or artefacts. Participants were faster in responding with a precision grip to objects graspable with a precision grip (e.g., pencils, cherries), and with a power grip to objects graspable with a power grip (e.g., hammers, apples) (see also [12]).

However, all behavioral studies conducted so far which showed a relationship between specific visual stimuli and specific motor responses typically required an activation of the motor system. Moreover, the kind of movement performed to provide the answer was relevant to the task.

For example, in the study by Craighero *et al.*[9], participants actually grasped a bar on presentation of the visual cue and the direction of the movement to perform was relevant to adequately grasp the bar. Similarly, Tucker and Ellis [32] instructed participants to press a device mimicking either a precision or a power posture, and the kind of grip performed to respond either matched or did not match the dimensions of the presented objects.

The aim of our study was to assess whether information on object manipulability may be automatically elicited by mere object viewing even when the motor system is not specifically called into play. To this end, in two experiments the movement performed to provide the answer was never relevant to the task. Participants had to press a different key to decide whether photos of objects represented artefacts or natural kinds. All objects were manipulable, half were graspable with a power grip (e.g., apple), and half with a precision grip (e.g., cherry). Objects to categorize were preceded by a prime consisting of photographs of hands displaying two critical postures (precision and power grip) and a catch-trial (an open hand). Experiment 2 differed from Experiment 1 as it was preceded by a motor training phase. Following the predictions of classic priming paradigms, faster responses should be expected when the prime shows a hand posture congruent with the posture required to manipulate the target object.

EXPERIMENT 1

The aim of Experiment 1 is to assess whether seeing an object automatically activates task irrelevant information regarding its manipulation. If this is the case, then two predictions can be made.

First, if visual objects activate motor information, target-objects graspable with a power grip should be processed faster than target-objects graspable with a precision grip, as in real life the processes underlying the implementation of a precision grip are more complex and time consuming than those required for a power grip ([13]). Such a finding would support brain imaging studies showing that the pre-motor areas are activated during the naming and viewing of pictures of manipulable objects ([8]; [17]).

Second, if a specific motor program (an action simulation) is activated by the prime, then a target object preceded by a prime that represents the hand posture adequate for its prehension (e.g., a cherry preceded by precision grip) should be processed faster than the same object preceded by an inadequate prime (e.g., a cherry preceded by power grip). This motor congruency effect between the hand posture and the way in which the object can be grasped (either with a precision or a power grip) should in turn lead to faster responses in object categorization. The neural substrate underlying the action simulation driven by the hand postures could be the "mirror neuron system", including neurons that fire when we either perform or observe a goal-directed action. A rich body of evidence obtained with brain imaging and neuro-physiological experiments has shown that a mirror neurons system does exist not only in monkeys but also in humans ([29]).

Method

Participants. Fourteen right-handed students of the University of Bologna took part in the experiment.

Materials. Digital photographs of a human hand displaying one of three different postures (precision grip, power grip, open hand) were selected as primes. Sixty-four photographs of manipulable objects (32 artefacts and 32 natural kinds) were selected as targets. All photos represented objects at the same size, independent from the actual size of the objects (for example, bottles were smaller and nuts larger than they are in real life). Special care was taken in selecting objects from everyday life. Half of the chosen objects were graspable with a precision grip (artefacts: needle, bus-ticket, button, screw, key, nail, knife, spoon, match, fork, pencil, pen, marking pen, tweezers, drawing pin, pencil sharpener; natural kinds: pine needle, peanut, rosebud, raisin, cherry, string bean, blade of grass, flower, leaf, strawberry, sprout, almond, hazelnut, nut, olive, pea). The other half was graspable with a power grip (artefacts: hair-dryer, jar, walking-stick, glass, bottle, candle, hammer, oil-cruet, umbrella, frying-pan, comb, dagger, salt-cellar, sword, tooth-brush, telephone; natural kinds: pineapple, orange, banana, onion, fennel, lemon, tangerine, apple, aubergine, corn-cob, potato, pepper, pear, peach, tomato, cucumber). In order to exclude biases in the selected materials, the frequency of the words corresponding to the objects as well as the object familiarity and frequency of use were controlled. Ten independent subjects rated object familiarity on a 7 points scale and 16 participants rated how often the objects were encountered and used in everyday life. We performed three ANOVAs on word frequency, familiarity and frequency of use, with the factors Object-Type (artefact/natural) and Grip (power/precision). Neither the main effects (Object-Type and Grip) nor the interactions were significant ($p > .1$).

Procedure. Participants sat in front of a computer monitor. Each trial began with a fixation point (+) displayed for 500 ms. Then one of the three hand photographs (prime) was displayed at the center of the screen for 600 ms, followed by a blank screen for 150 ms, then by the photograph of one of the objects (target), which remained on the screen until a response was made. When the prime consisted of a hand mimicking a precision or a power grip, participants had to decide as fast and accurately as possible whether the subsequent target represented a natural object or an artefact by pressing one of two designated keys. When the prime depicted an open hand (catch-trial), they had to refrain from responding. Half of the participants associated a right button press to artefacts and a left button press to natural objects, whereas the opposite matching applied to the other participants. Participants received feedback for both correct and incorrect responses. Each object was presented three times, each time preceded by a different hand prime, in random order. The experiment consisted of one practice block of 48 trials and one experimental block of 192 trials.

Results

Reaction times (RTs) more than 2 standard deviations from each participant's mean, as well as RTs for incorrect responses, were excluded from the analyses of both experiments. Correct RTs and errors were entered into a 2x2x2 within-subject ANOVA with the following factors: Prime-Target Compatibility (compatible, incompatible), Target-Type (artefact, natural kind), and Target-Grip adequate for the target object (precision, power grip). Analyses of errors, that accounted for 4% of response trials in both experiments, revealed no evidence of a speed accuracy trade-off.

No main effect was significant. Interestingly, however, the interaction between Target-Type and Target-Grip was significant in both RTs and errors, $F(1, 13) = 8.39$, $MSe = 477.21$, $p < .02$ (see Figure 1); $F(1, 13) = 6.34$, $MSe = 0.41$, $p < .03$: natural kinds graspable with a power grip were faster than all other objects[1] (Newman-Keuls, $p < .01$). Surprisingly, no effect of prime was observed.

Discussion

The advantage observed for natural power objects suggests that seeing objects activates motor information. From the point of view of the embodied theory of cognition, there are two reasons why this might happen. First, grasping an object with a power grip is easier than grasping it with a precision grip. Thus, it is not surprising that if a visual stimulus leads to the simulation of an easier grasping experience ([1]; [16]; [19]; [29]), its overall processing time should be shorter. Second, studies on conceptual organization have shown that the recognition of artefacts depends more on functional features (e.g., “used to drink”) than the recognition of natural objects, for which visual features are more relevant (e.g., “brown”) ([6]; [34]). In this respect, a further distinction can be made: artefacts are more frequently associated with information regarding how to use them properly (“what for?”), whereas natural kinds are mainly associated with information regarding how to reach, grasp and manipulate them (“how?”) (for a review see [2]). If an artefact activates information not only about how to manipulate it, but also about the functional gestures associated with it, it could be argued that seeing an artefact leads to the simulation not only of the hand gestures required to grasp it, but also of the other gestures required to actually use it. This would not be the case for natural objects. The advantage observed for natural power could thus be due to the fact that these items induced a simpler ‘simulation’ of action (grip) but not function.

Even though such an advantage can be explained in terms of the activation of motor information, the absence of the compatibility effect between prime and target leads us to exclude the hypothesis that a specific motor program was triggered by a specific visual prime. There are two possible explanations The first possibility is that participants did not pay enough attention to the prime. However, the low percentage of errors with catch-trials ruled out this explanation. The second explanation is that, even if the visual prime elicited information on grasping objects, it was not sufficient to trigger a specific motor program (i.e. a precision vs. a power grip). Experiment 2 was conducted to test this possibility.

EXPERIMENT 2

On the basis of previous findings indicating that motor training conducted prior to the conceptual task induced better performance for compatible conditions ([4]; [25]), in Experiment 2 we introduced a motor training phase with the aim of strengthening the association between prime and target. During this training phase participants were required to reproduce the hand gestures shown as primes. As for Experiment 1, we predict that a target object which requires a grip compatible with the activated, primed grip should be processed faster than an object that requires an incompatible grip.

Method

Participants. Forty right-handed students of the University of Bologna participated in the experiment.

Materials and procedure. They were the same as those used in Experiment 1 with the addition of a training phase. During the training phase, the two photographs of a hand displaying the precision and the power posture were shown in a random order and were presented 15 times each, for a total of 30 trials. Participants were instructed to reproduce with both hands the gesture seen on the screen. An experimenter checked to be sure that participants correctly performed the task. Immediately after the training phase, participants started the experiment.

Results and discussion

The data of one participant were eliminated due to an overly high number of errors (more than 10%). The main effect of Target-Type was significant in both RTs and errors: participants responded to natural kinds 24 ms faster than to artefacts, $F(1, 38) = 17.67$, $MSe = 2839.17$, $p < .001$; $F(1, 38) = 7.50$, $MSe = 4.38$, $p < .01$. Most importantly, we found the predicted Prime-Target Compatibility effect, $F(1, 38) = 6.19$, $MSe = 510.12$, $p < .02$, due to the fact that compatible trials produced faster RTs than incompatible ones (see Figure 2). The interaction between Target-Type and Target-Grip was significant in both RTs and errors, $F(1, 38) = 18.03$, $MSe = 582.85$, $p < .001$; $F(1, 38) = 25.66$, $MSe = 0.78$, $p < .00001$. Participants responded faster and more accurately to natural power objects than to other objects (Newman-Keuls, $p < .01$) (see Figure 3).

The results show that visual primes combined with an activation of the motor system facilitate the processing of objects compatible with the primed hand posture. This suggests that the training phase increased participants' sensitivity to the congruency between prime and target.

GENERAL DISCUSSION

Across the experiments we found that seeing photographs of objects activated information regarding how to manipulate and use them. Though behavioural in nature, this result is critical for models of knowledge organization in the brain. Namely, our results support the IDOMA theory, according to which information is distributed in the brain over visual and motor attribute domains to the degree to which these attributes were activated during knowledge acquisition.

In addition, our results have implications for the literature on the relationship between vision and motor commands. In their influential book, Milner and Goodale [26] propose that the ventral stream of cortex, which code the perceptual representation of an object, and the dorsal stream, which is involved in transforming visual information into motor commands, are relatively independent. Our results show that visual representation and visuomotor coordination are closely interwoven. In line with recent behavioural and neuroimaging evidence, this suggests that a representation of the object is coded also in the dorsal visual stream ([8]; [18]; [20]).

The finding that participants were faster at categorizing natural power objects indicates that seeing photographs of objects activated information regarding how to manipulate and use them. Such advantage over the other object types could be accounted for by the fact that these items induced a simpler simulation of action (grip) but not functional knowledge. The result is consistent with brain imaging and neuropsychological studies that suggest that action and function knowledge do not overlap ([5]; [23]; [31]).

The fact, however, that priming effects emerged only after a motor-training phase (Experiment 2) shows that visual objects do not activate motor information irrespective of the state of activation of the motor system. Previous evidence confirms that visual primes alone might not be sufficient to evoke specific motor programs. For example, Klatzky *et al*. (1989) found that semantic judgements about actions were facilitated if preceded by a visual prime that matched the action referred to in the sentence – for example, the sentence "aim with a dart" was processed faster when preceded by a pinch posture than by other postures. Crucially, before the experiment participants learned to associate the prime to a specific gesture, which they were asked to perform (for similar results with a naming task see [4]). Given the fact that the visual prime alone was not sufficient to elicit a specific motor program, what kind of process could have occurred during the training phase of Experiment 2? According to the Theory of Event Coding (TEC), perceptual contents and action plans are coded in a common representational map ([22]). In this view, the contents of perception and action are commensurable as they both represent events in the environment. They cannot, therefore, be conceived of as separate and sequential processes. Rather, each one influences the other in a reciprocal fashion. The more similar an observed action is to the codes that govern one's own action planning, the higher the activation of these codes. Given that common codes are more fully activated when an individual observes his/her own actions than when observing others' actions, the training phase could have led participants to match their own actions with the actions they saw, thus becoming sensitive to the different motor programs triggered by the two primes. In line with our results, in a recent study on the mirror system Grezes *et al.* [21] recorded the brain activity of observers watching a video of themselves and other people. The observation by an individual of his/her own action produced faster activation of the parietal pre-motor areas than the observation of other people's actions, probably due to the closer match between participants action simulation and the actions in the videos.

In other words, our study suggests that the visual primes alone were not sufficient to induce "motor resonance" behaviour in participants. Motor resonance, which is mediated by the mirror neuron system, is characterized by the occurrence, upon observation of an action, of the same neural pattern that is activated while performing the observed action ([30]). As recent evidence suggests ([14]; [15]), it is possible that in our Experiment 1 participants did not automatically use their body to 'simulate' other persons' actions. The training phase that required participants to use their own body to reproduce the postures they saw, might have induced motor resonance behaviour. This motor resonance would explain the prime-target compatibility effect. Interestingly, the compatibility effect found in our experiments has implications for understanding the human mirror neuron system. Namely, it supports the view that the human brain contains a neural circuitry sensitive to the fine discrimination between kind of grips (e.g., precision, power). That is, it appears that there are "strictly congruent" mirror neurons that encode not only the goal of an action but the means for obtaining it as well (e.g., the kind of grip to use). Literature on mirror neurons show that "strictly congruent" mirror neurons represent the minority of the monkey mirror neurons, whereas the majority of neurons fire also when observed and performed grasp differ. Recent studies suggest that this distribution might be different in humans [29].

In this perspective, we conclude that visual stimuli are sufficient to evoke motor information as photographs of objects automatically activate general information on how to manipulate and use objects. However, for a specific motor priming to emerge, participants have to be trained to reproduce the gestures depicted in the primes in order to induce a stronger association with the hand-postures they would adopt to interact with specific target-objects.

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Notes

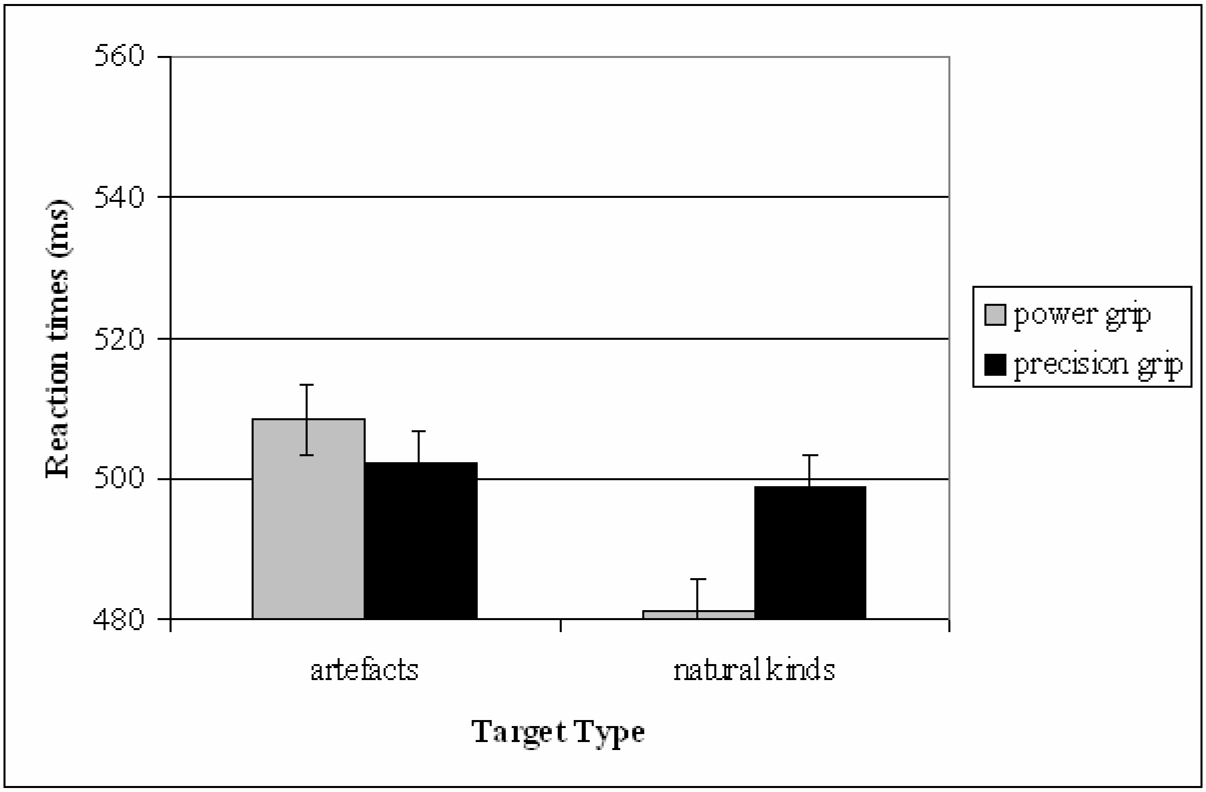
[1] In order to be sure that the effect was not due to items prototypicality, 16 participants evaluated on a 7 points scale how much each item was typical of its category (e.g., “how much an apple is a typical natural object”). The difference between power and precision natural kinds was not significant (ANOVA, $p > .1$).

Figure captions

Figure 1. Experiment 1. Interaction between Target-Type and Target-Grip. Natural kinds graspable with a power grip were faster than all other objects.

Figure 2. Experiment 2. Prime-Target Compatibility. Compatible trials (power/power and precision/precision) were faster than Incompatible ones.

Figure 3. Experiment 2. Interaction between Target-Type and Target-Grip. Natural kinds graspable with a power grip produced faster RTs than all other objects.



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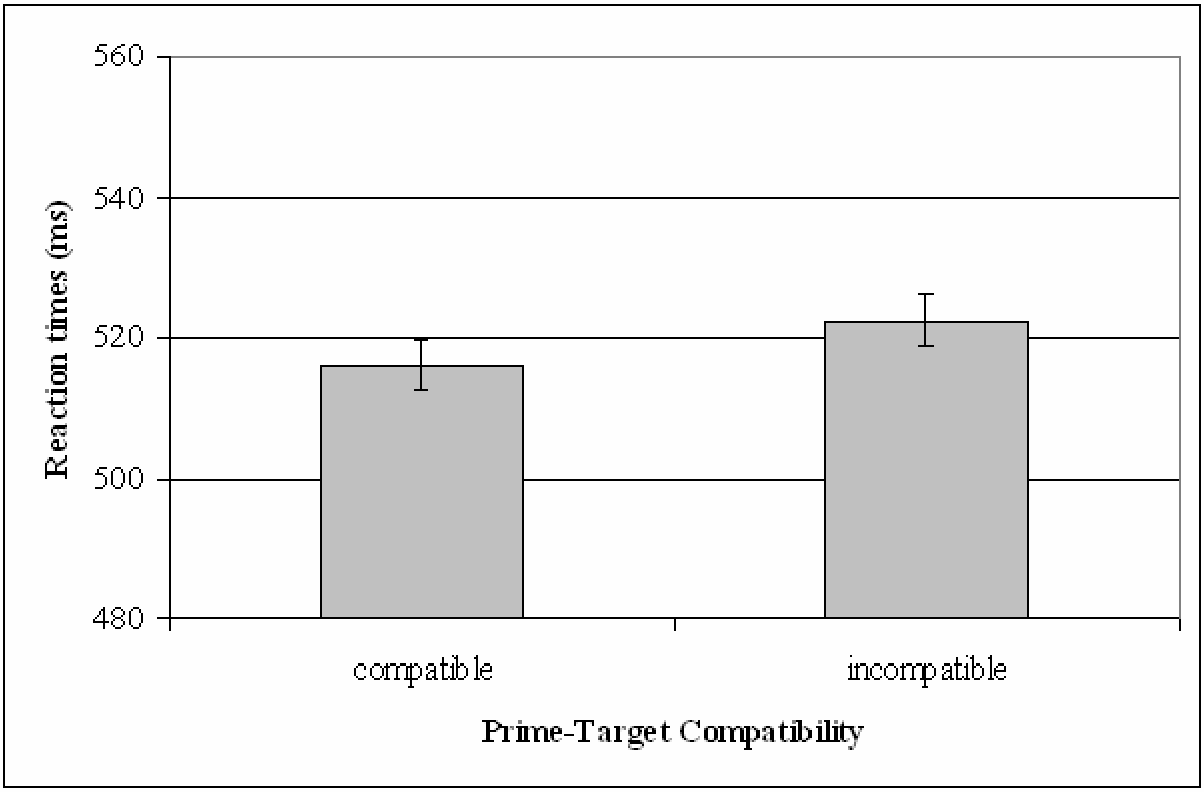

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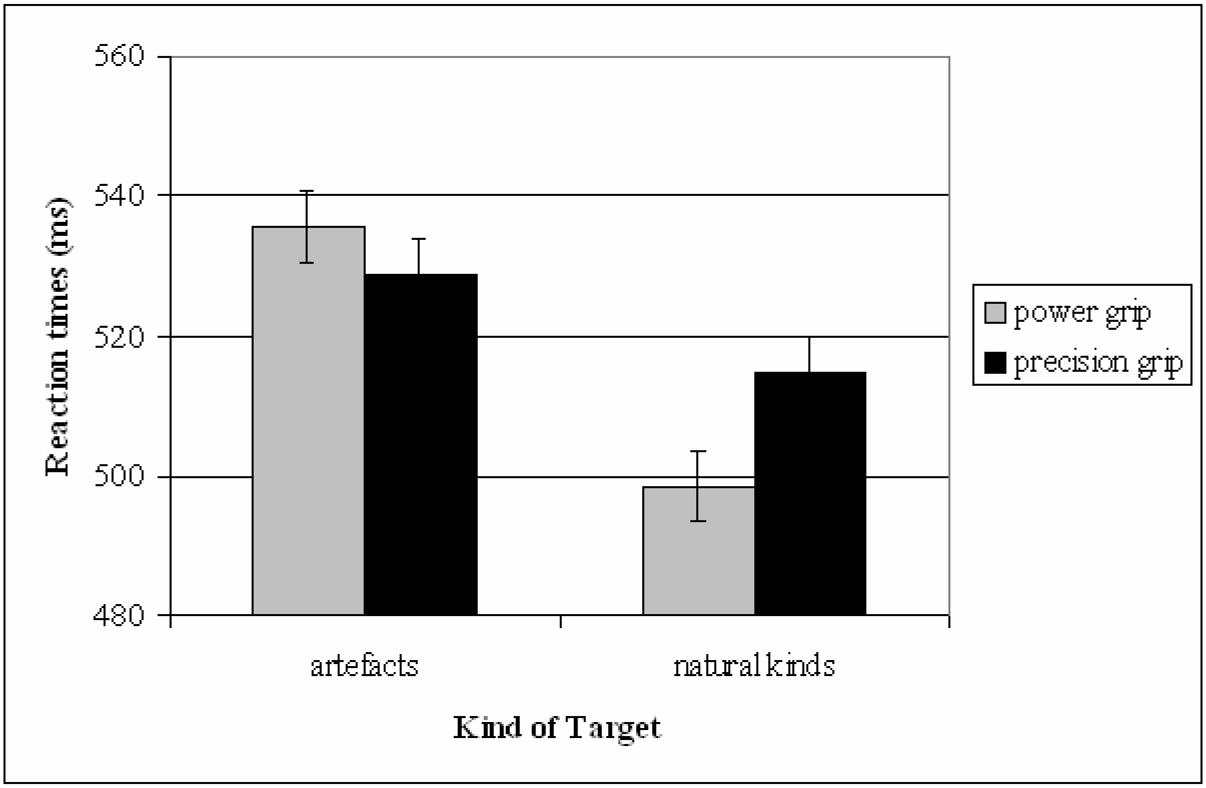

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