Psychological Research (2015) 79:928–938
DOI 10.1007/s00426-014-0622-0

ORIGINAL ARTICLE

How do you hold your mouse? Tracking the compatibility effect between hand posture and stimulus size

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Received: 20 February 2014 / Accepted: 10 October 2014 / Published online: 28 October 2014

Abstract In keeping with the idea that observing objects activates possible motor responses, several experiments revealed compatibility effects between the hand postures used to report a choice and some characteristics of the stimuli. The real-time dynamics of such compatibility effects are currently unknown. We tracked the time course of a categorization experiment requiring subjects to categorize as natural or artifact figures of big and small objects. Participants reported their choice using either a big mouse (requiring a power grip: a hand posture compatible with the grasping of big objects) or a small mouse (requiring a precision grip: a hand posture compatible with the grasping of small objects). We found a compatibility effect between the grip required by the mouse and the grip elicited by objects, even if it was irrelevant to the task. In a following experiment with the same paradigm, lexical stimuli failed to reproduce the same effect. Nevertheless, a compatibility effect mediated by the target-word category (artificial vs. natural) was observed. We discuss the results in the context of affordance effects literature and grounded theories of cognition.

Introduction

The ability to grasp objects in the appropriate way, using the adequate kind of grip and timing of opening and closing the hand, represents one of the more complex and sophisticated motor abilities humans are endowed with, as its progressive refinement during development testifies. Grasping has been mostly studied in the framework of motor control (Oztop & Arbib, 2002; Shadmehr, Smith, & Krakauer, 2010), but in the last years the interest for grasping actions and grasping postures has risen in the literature on visuo-motor transformations and affordances. Building on the notion of affordance proposed by (Gibson, 1979), according to which objects invite organisms to act, recent studies have shown that observing objects activates possible motor responses.

Studies on action preparation have provided evidence of a shifting of attention toward the action-relevant property of the objects, leading to compatibility effects between the hand posture used to respond and some characteristics of the stimuli. For example, Craighero, Bello, Fadiga, and Rizzolatti (2002) asked participants to prepare to grasp a bar that could have different orientations; when the picture of a hand was displayed, they had to grasp the bar as fast as possible. Results revealed a compatibility effect between the orientation of the bar (clockwise, counter-clockwise) and the final position of the grasping hand. Most relevant to the present work are studies on the affordance-based compatibility effect between the object size and the kind of grip used to respond. In an influential work, Tucker and Ellis (2001) instructed participants to categorize as “natural” or “artifact” various real objects differing in size; participants reported their response by mimicking either a precision or a power grip with a customized device. The compatibility effect they found between the object size

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(large, as apple, hammer, or small, as cherry, nail) and the grip used to respond (power or precision) indicates that observing objects potentiates their affordances. Importantly, the action-relevant dimension (i.e., size) influenced response times even if it was not relevant to the categorization task. Further experiments with briefly presented objects (Tucker & Ellis, 2004) revealed that the effects are maintained even when the objects disappear, showing that they do not need to be visible during the response selection; additionally, also the presentation of object names exerted the effects. The reported compatibility effects thus seem to be due to long-term associations between objects and actions. Further recent studies have investigated the compatibility effects induced by the context. In some studies the context was given by the presence of a hand in potential interaction with the object and by another object which might be functionally connected to the first or not (e.g., Borghi, Flumini, Natraj, & Wheaton, 2012; Natraj et al., 2013; Yoon, Humphreys, & Riddoch, 2010). In a recent work, Kalénine, Shapiro, Flumini, Borghi, and Buxbaum (2014) used conflict objects, (i.e., objects that had different affordances related to use and to movement, Jax & Buxbaum, 2010; Lee, Middleton, Mirman, Kalenine, & Buxbaum, 2013; see also Bub, Masson, & Cree, 2008; Creem & Proffitt, 2001) and found that the compatibility effect between hand postures (precision vs. power) and objects was modulated by the visual scene in which objects were embedded, eliciting either use-related or move-related actions.

Further studies on visuo-motor priming investigated the effect of showing different hand postures on subsequent tasks. Vogt, Taylor, and Hopkins (2003) and Bruzzo, Borghi, and Ghirlanda (2008) manipulated the perspective of the hand prime demonstrating its effect on grasping and categorization tasks. More relevant to the present work are studies on compatibility effects between the hand posture and the object size. Borghi et al. (2007) asked participants to categorize pictures of objects differing in size into “artifact” and “natural” by pressing two different keys on the keyboard; the stimuli were primed by pictures of hands displaying either a precision or a power grip. A compatibility effect between the hand prime (power, precision) and the object size (large, small) was found, provided that before the experiment participants mimicked the displayed hand postures. The compatibility effect between the hand prime and the size of the targets was replicated and extended by Vainio, Symes, Ellis, Tucker, and Ottoboni (2008) with dynamic hand stimuli.

As this brief overview shows, a number of experiments have demonstrated the presence of an interaction between the hand posture and objects action-based characteristics, particularly size. In some studies different hand postures were used to provide the response, in other studies different hand postures were displayed as primes. In both cases compatibility effects were found. Overall, the evidence on the interaction between hand posture and object size raises questions about the factors that influence the involved processes and their time course. However, to our knowledge no study so far has focused on how the effects of the compatibility vs. incompatibility between the information derived from the object and the hand posture unfolds in time and is reflected in an explicit movement. In the present study, we intend to investigate the time course of the congruency effect. Our aim is to assess when does the conflict between the information derived from the posture of the hand used and the object size come into play, and how it is reflected in overt movements. In addition, we intend to verify the role played by a distractor compatible in size with the target in deviating the trajectory to reach the object.

With respect to the current literature, our work presents several novelties. The first is that it investigates static hand postures rather than full prehension movements. We used a mouse that participants held and dragged with their dominant hand; the mouse could be small, graspable with a precision grip, or large, graspable with a power one, but in both cases the task required participants to assume static hand postures. In previous studies on affordance-based compatibility participants were either required to simply press a button on the keyboard (e.g., Borghi et al., 2007, 2012; Riggio et al., 2008; Fagioli, Hommel, & Schubotz, 2007) or alternatively they were asked to squeeze a device mimicking a power grip and to press a switch mimicking a precision grip (e.g., Tucker & Ellis, 2001); this resembles more to the experience of squeezing some fruit or vegetable, while artifacts are often hard and not squeezable (Anelli, Nicoletti, & Borghi, 2010). Rather, in real life we often use static precision and power postures when we hold or use objects: we hold nails and nuts, coconuts and umbrellas, etc. Our study uses small or big mouses that require similar static hand postures, thus increasing its ecological validity.

Using the mouse has a further advantage, which represents the second novelty of our study. In the experiments conducted by Tucker & Ellis (2001, 2004) the hand posture was relevant for the response to provide, while in studies with hand primes (e.g., Borghi et al., 2007) it was not, since a simple keypress response was required. In our study, participants’ motor response consists in moving the mouse in different directions regardless of how the mouse is grasped. Participants saw a cue-word on the screen (“artificial” vs. “natural”) and were instructed to drag the mouse to two different locations to decide which of the displayed images represented an object of the category indicated by the word. Dragging the mouse toward the target mimicked the reaching of the object. Objects were either natural or artificial, and differed in size: they were either graspable with a precision vs. a power grip. Similar to the original study by Tucker and Ellis (2001), participants' hand posture was irrelevant to the task but was manipulated–by providing participants with small or big mouses–to unveil compatibility effects with stimuli dimensions (e.g., size of target and distractors). To ensure that grasping the mouses required a precision (small mouse) and power (big mouse) grasp, we selected mouses whose (horizontal) dimension matched two typical stimuli used in Tucker and Ellis (2001) and related paradigms: a plum (small mouse) and an orange (big mouse).

The third important novelty of the present work is that we used a continuous measure of performance: we tracked participants' mouse trajectories during the choice. This procedure is increasingly used to study the real-time dynamics of decision and is particularly useful to reveal the fine-grained effect of conflicting cognitive processes (Barca & Pezzulo, 2012; Freeman & Ambady, 2010; Lepora & Pezzulo, submitted; Quinton, Catenacci, Barca, & Pezzulo, 2014; Song & Nakayama, 2009). It allows studying the real-time dynamics of choice and to measure uncertainty during the choice that depends on both the inherent complexity of the task and the 'intrusion' of conflicting information (in principle) irrelevant to the task demand. Tracking the mouse in psychological sciences, for example, has been used to reveal the role of social cues in face categorization (Freeman, 2014), and the spatial organization subtended to the temporal dimension (Flumini & Santiago, 2013). Furthermore, it has been used to demonstrate that greater gender-category competition predicted a decreased likelihood of votes, but only for female politicians (Hehman, Carpinella, Johnson, Leitner, & Freeman, 2014), and that irrelevant phonological information can "intrude" a spoken word recognition task and bias mouse trajectories (Spivey, Grosjean, & Knoblich, 2005). Given the richness of the collected measures, there are several degrees of freedom in the types of analyses that might be adopted. Much depends on the research issues but, for example, several techniques have been developed to examine the onset and timing of evolving decision processes, or to test the competition between response alternatives at different time points, and to assess movement complexity with spatial disorder analyses (for details see Hehman, Stoiler, & Freeman, 2014).

In our study, the mouse-tracking procedure allows us to investigate the effect played by congruent or by conflicting information as it unfolds in time and is reflected in hand movements. The trajectory followed while moving the mouse to reach for the object can provide evidence about the effects of congruent or conflict information on the response selection. To our knowledge the only study investigating similar issues is an EEG experiment conducted by Goslin, Dixon, Fischer, Cangelosi, and Ellis (2012) on compatibility effects between the response hand and the handle location of objects. Results revealed that visual processing and motor information are integrated very early, before 200 ms of stimulus onset (see also Bub & Masson, 2010, on the dynamics of aligned effects elicited by handled objects).

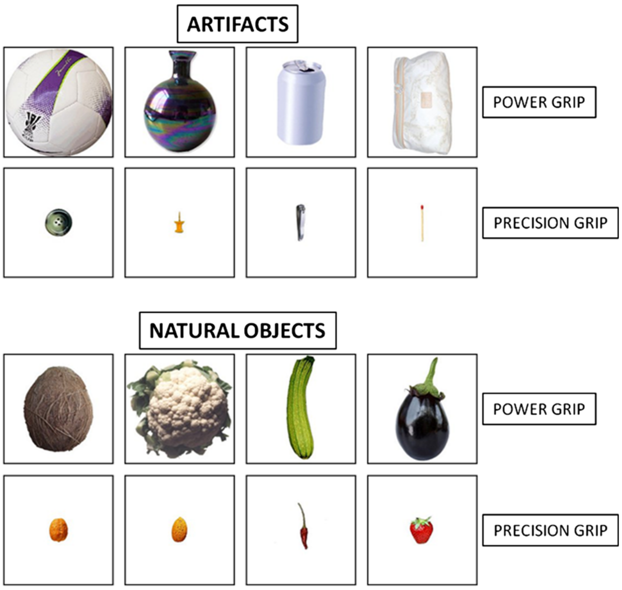

Fig. 1 Sample stimuli used in the experiment

If participants are sensitive to static hand postures and this sensitivity is reflected in the trajectory followed while reaching for the target object, we predict a compatibility effect between the grip required by the mouse (power, precision) and the grip elicited by the target object (small, big). Thus, the curvature of the reaching trajectory, plausibly reflecting the degree of uncertainty in the decision process and the possible intrusion of conflicting information (Bruhn, Huette, & Spivey, 2014; Spivey, 2007), should be higher when the target and the mouse are not compatible in size.

Experiment 1

Method

Participants

Twenty-four under graduated students from the University of Bologna (9 males; mean age = 21.25 (2.88); all Italian monolingual and right-handed by self-report) participated for course credits. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment.

Materials

Participants performed a semantic categorization task. They were presented with color images of everyday objects. Sixteen pictures were used, 8 depicting natural objects and 8 depicting artifacts. Within each category, 4 objects afforded a power grip (e.g., 'courgette') and the other 4 afforded a precision grip (e.g., 'nut'). Two pictures were presented in the upper corners of the screen, one depicting an artifact and one depicting a natural object (i.e., one target and one distractor). Pictures were preceded by the central presentation of the word 'artificial' or 'natural', which instructed the participants on which item they had to click with the mouse to respond correctly. Stimuli were combined in 64 pairs presented twice, once for the categorization of the 'artificial' target, once for the categorization of the 'natural' target.

Objects' images were scaled to preserve the real size differences, and each image was always presented in a 200 × 250 pixels box, color print on white background (see Fig. 1).

Design and procedure

Participants sat 60 cm from the computer screen, with their right hand placed over the mouse they found in front of them, already positioned to begin the experiment.

Each trial began with the appearance of the 'start' button (displayed at the bottom-centre of the screen) that remained on the screen until a single mouse-click was performed on it. The cue-word ('artificial' or 'natural') was displayed after the mouse-click at the centre of the screen for 1,500 ms (50 % of the trials were preceded by the word 'artificial', the other half by the word 'natural'). Then, the two experimental stimuli appeared on the top-left and top-right corners of the screen and remained on the screen until a response was made by mouse-clicking on one of them. Participants were instructed to decide which among the two stimuli matched the category indicated by the cue-word (see Fig. 2). They were asked to respond as quickly and accurately as possible. A feedback message was provided in case of incorrect response (a red 'X' at the centre of the screen). To avoid any repetition effect, pairs of stimuli were presented in random order.

Stimuli were presented in two blocks where mouse dimension was also manipulated, so that in one block participants were asked to respond using a big mouse (length 11 cm, width 6 cm, height 3.5 cm) and in the other block they had to use a small mouse (length 7 cm, width 3.5 cm, height 2.2 cm). Each block consisted of 128 experimental trials preceded by 4 training trials, so each participant responded overall to 8 training trials and 256 experimental trials. The two pointing devices had default settings, with medium gain.

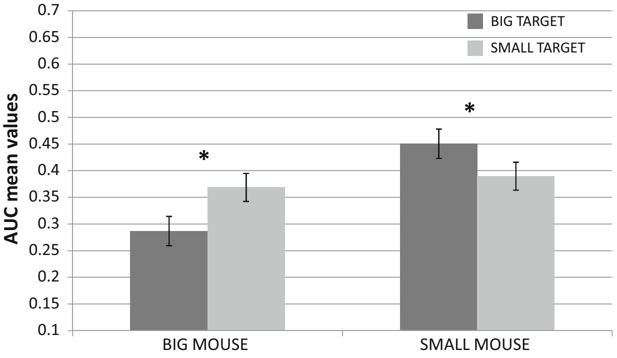

Fig. 2 Experiment 1—interaction response device × target dimension (AUC mean values)

In each experiment the following factors were manipulated: response device (big mouse/small mouse), target type (artifact/natural), target dimension (big/small).

MouseTracker software was used for stimulus presentation and data collection (Freeman & Ambady, 2010): an open-source software package, freely available at the web page http://psych.nyu.edu/freemanlab/mousetracker/, which allowed us to record and analyze the continuous stream x–y coordinates of the hand movements performed by participants who decided among alternative responses. Thus, precise characterizations of both temporal and spatial dynamics of the mouse trajectories were available to be analyzed. Individual trajectories were first rescaled to a standard coordinate space and then normalized into 101 time steps using linear interpolation (see Freeman & Ambady, 2010).[1] Data were then exported in Microsoft Office Excel using the utilities included in the MouseTracker package, then trimmed in Excel, while all the ANOVAs were performed in StatSoft STATISTICA 6.0.

Data analysis and results

Accuracy, initiation time and trajectory time

We removed 0.98 % of trials as errors. This very low rate of errors reveals that the task was easy to perform. Total trajectories times exceeding 2 standard deviations from each participant's mean were excluded from the analysis,

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[1] Time normalization is conducted because each trajectory tends to have a different length. To permit averaging and comparison across multiple trials, the x–y coordinates of each trajectory are normalized into a given number of time-bin (in our study we choose 101 time-bin) using linear interpolation as available in the MouseTracker software (http://psych.nyu.edu/freemanlab/mousetracker/). Thus, each trajectory is normalized to have 101 time-bins, and each time-bin has a corresponding x and y coordinate.

leading to the removal of additional 8.27 % of the data. The total trimming was of the 9.25 % of trials.

The remaining data were entered into a 2 × 2 × 2 within subjects ANOVA, with the factors response device (big mouse vs. small mouse), target type (artifact vs. natural) and target dimension (big vs. small). Where possible, interaction effects were evaluated with Newman-Keuls post hoc test ($p < 0.05$).

The ANOVA on Initiation times showed significant main effects of response device and target type. The time to initiate the movement was longer when using the big mouse than when using the small mouse (422 and 290 ms, respectively; $F(1, 23) = 58.19$, MSE = 14,537.1, $p < 0.001$); and for categorizing natural than artifact items (364 and 348 ms, respectively; $F(1, 23) = 9.13$, MSE = 1,332.3, $p < 0.01$). No other main effects or interactions were significant.

The different size of response devices implies also a difference in their weight and friction, which might be partly responsible for the observed effect on initiation time. Given such side effect, no theoretical conclusion will be drawn on the effect of mouse dimension on temporal measures of the response.

The analyses on total trajectory times, which here are the overall response times, revealed as significant the main effect of target type [$F(1, 23) = 15.39$, MSE = 4,402.52, $p < 0.001$] with faster response for natural ($M = 1{,}312$ ms) than artifact ($M = 1{,}350$ ms) items. No other main effects or interactions were significant.

Trajectory spatial analysis

The area under the curve (AUC)[2] is a measure of spatial attraction towards the opposite response alternative, i.e., the distractor item the influence of which has to be suppressed to give the correct response. Positive AUC mean values indicate that the mouse trajectory is above the idealized straight line between the START button and the target-object. Thus, the AUC values measure how much the hand movement is attracted toward the distractor item, indexing the indecision during the choice.

The ANOVA on AUC demonstrated the main effects of the factors response device and target type. An interaction was reliable as well, whereas another almost reached significance.

The response device main effect showed that the big mouse mean AUC ($M = 0.33$) was smaller than the small mouse mean AUC ($M = 0.42$), $F(1, 23) = 7.67$, MSE = 0.05341, $p < 0.05$, probably due to the lightness of the small mouse (more subject to involuntary deviations). The factor target type, $F(1, 23) = 11.98$, MSE = 0.03897, $p < 0.01$, was significant because the natural items AUC ($M = 0.32$) was smaller than the artifacts AUC ($M = 0.42$).

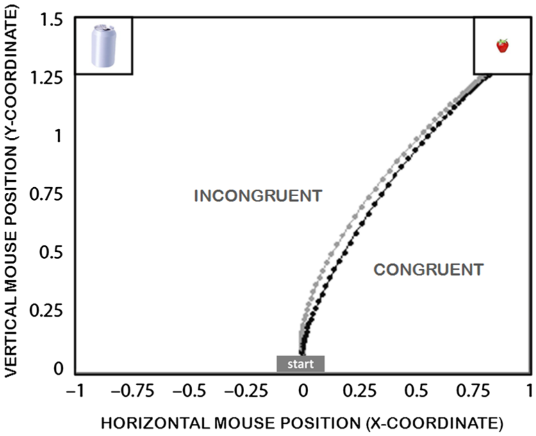

Fig. 3 Experiment 1—congruent (*black line*) vs. incongruent (*grey line*) trials, plot of the mean trajectories

As expected, the interaction of response device and target dimension was significant, $F(2, 46) = 10.9$, MSE = 0.02203, $p < 0.01$, confirming our prediction about a compatibility effect between the hand posture and the dimension of the target. Indeed, when participants were using the Big mouse it was easier to go straight over a big target-object ($M = 0.29$) than a small one ($M = 0.37$) (Newman-Keuls $p < 0.05$), while the opposite was true when using the small mouse, with greater AUC for big target-object ($M = 0.45$) than for small ones ($M = 0.38$) (Newman-Keuls $p < 0.05$, see Figs. 2, 3).

Finally, the target type × target dimension interaction, $F(2, 46) = 3.63$, MSE = 0.01534, $p = 0.07$, almost reached significance. It showed that when the target stimulus was an artifact it was easier to go straight to a small target ($M = 0.41$) than to a big one ($M = 0.44$), while the opposite was true for natural target stimuli (big target $M = 0.30$, small target $M = 0.34$). No other main effects or interactions were significant.

The maximum deviation (MD)[3] is a further measure of spatial attraction to the opposite response alternative. It determinates which of the points in the trajectory is the most far from the idealized straight line between the START button and the target-object by measuring the perpendicular line from that point to the idealized straight line. As for the AUC, positive MD mean values indicate

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[2] The AUC of a trajectory is calculated as the geometric area between the actual trajectory and the idealized straight trajectory connecting the start with the end point of the movement. Area on the opposite side (i.e., in the direction away from the unselected response) of the straight line is calculated as negative area.

[3] The MD of a trajectory is calculated as the largest perpendicular deviation between the actual trajectory and an idealized trajectory connecting the start and end point of the movement, out of all time-steps. Thus, the higher the MD, the more the trajectory deviated toward the unselected alternative.

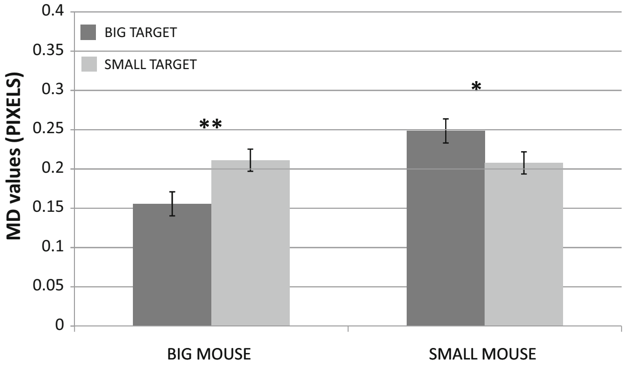

Fig. 4 Experiment 1—interaction response device × target dimension (MD mean values)

that the mouse trajectory is above the idealized straight trajectory, so the MD values index again how much the hand movement is attracted toward the distractor item.

The ANOVA on MD demonstrated the main effects of the factors response device and target type. Two interactions were reliable as well.

The factor response device was significant due to the big mouse mean MD ($M = 0.18$) being smaller than the small mouse mean MD ($M = 0.23$ ms), $F(1, 23) = 6.10$, $\text{MSE} = 0.01578$, $p < 0.05$ (probably for the lightness of the small mouse). The factor target type, $F(1, 23) = 14.61$, $\text{MSE} = 0.00863, p < 0.001$, showed that the natural items MD ($M = 0.18$) was smaller than the artifacts MD ($M = 0.23$).

The interaction of the factors response device and target dimension was significant in this measure too, $F(2, 46) = 16.63$, $\text{MSE} = 0.00651$, $p < 0.001$. This further confirmed our prediction of a facilitation effect in case of compatibility between hand posture and target-object dimension. Indeed, when participants used the big mouse it was easier to go straight over a big target-object ($M = 0.16$) than over a small one ($M = 0.21$) (Newman-Keuls $p < 0.01$); the opposite was true when using the small mouse, with greater AUC for big target-object ($M = 0.25$) than for small target-object ($M = 0.21$) (Newman-Keuls $p < 0.05$) (see Fig. 4).

The target type × target dimension interaction, $F(2, 46) = 5.24$, $\text{MSE} = 0.00422$, $p < 0.05$, was reliable as well. When the target stimulus was an artifact it was easier to go straight to a small target ($M = 0.22$) than to a big one ($M = 0.24$), and the opposite was true for natural target stimuli (big target $M = 0.17$, small target $M = 0.20$) (Newman-Keuls $p < 0.05$). No other main effects or interactions were significant.

Discussion of experiment 1

The continuous recording of mouse movements allowed us to study the influence of participants' hand postures and target object size. We found that response trajectories were affected by the power grip required by a big mouse and the precision grip required by the small mouse. The results confirmed our prediction of a compatibility effect between mouse dimension and stimuli. We found the predicted compatibility effect in both MD and AUC: the trajectories followed by participants were more direct, revealing less uncertainty in the decisional process, when the dimension of the mouse and the object size matched. In addition, we found a clear influence of the distractor size on the response. When the dimension of the mouse matched with that of the distractor, responses were more uncertain, as the interaction on MD indicated. Furthermore, the degree of uncertainty as revealed by AUC was higher when the object and the distractor size matched than when they did not. This result is predicted by common coding theories: inhibition effects should arise in case of simultaneous activation of the same code from multiple sources (e.g., TEC, Hommel, Müsseler, Aschersleben, & Prinz, 2001). Overall, these results reveal that participants were sensitive to the static hand posture they used, and that the compatibility effect was present even if the object size was neither relevant to the task, a semantic categorization, nor to the response provided, consisting in moving the mouse in a given direction. To our knowledge this is the first evidence of compatibility effect between object size and static hand posture; importantly, the effect is obtained analyzing the trajectory of a reaching movement.

Further results, less crucial for our main hypotheses, confirm and extend previous findings in the literature. They complement studies showing that responses to artifacts are slower than to natural objects (Borghi et al., 2007; Vainio et al., 2008) demonstrating it with novel, continuous measures. This might appear counterintuitive, since artifacts are designed to be used, but as suggested in the literature it is probably due to the fact that they do not only activate manipulation but functional information as well, and also to the fact that these two kinds of information might collide and compete (Jax & Buxbaum, 2010).

The effects obtained raise the issue of whether and to what extent our effects depend on online computation (plausibly supported by the dorsal stream) or on information stored in memory. To better investigate this issue, we performed a second experiment in which we presented the names of the objects instead of the images.

Experiment 2

Experiment 2 differed from experiment 1 only for the stimuli, which consisted of words. Previous studies with response times have found a compatibility effect with both objects and words (Tucker & Ellis, 2004). We therefore, intended to test three alternative hypothesis. The first, more directly derived from and in keeping with "classical" embodied cognition view (e.g., Fischer & Zwaan, 2008; Jirak, Menz, Buccino, Borghi, & Binkofski, 2010), is that words are grounded in perception and action systems. The second view is the standard propositional one: processing of words would radically differ from processing of objects because the former would be represented in a propositional, arbitrary and abstract way. According to the third view, derived from theories of reuse (Anderson, 2010; Pezzulo & Castelfranchi, 2009; Gallese, 2008), words are grounded in perception and action systems, but language processing differs to some extent from processing of objects. Language is indeed a rather sophisticated ability, hence word processing might not reflect all the dynamics characterizing processing of their referents (Borghi, 2012). The three views generate differential predictions. The first view predicts that a compatibility effect will be found with words as well; the second view predicts that no compatibility effects will be found; the third view predicts that we should find evidence that words are grounded (for example, they should be sensitive to the size of their referents) but the results obtained with words should not necessarily mirror those obtained with objects.

Method

Participants

Twenty-four under graduated students from the University of Bologna [12 males; mean age = 22.37 (3.19); all Italian monolingual and right-handed by self-report] participated for course credits. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment.

Materials, design and procedure

Participants performed the same semantic categorization task of experiment 1. In this case, they were presented with the names of the 16 objects of experiment 1. Linguistic stimuli were presented in a 200 × 250 pixels box in ARIAL font upper case, black print on white background. Experimental procedure and task instructions were exactly the same as in experiment 1.

Data analysis and results

Accuracy, initiation time and trajectory time

We removed 2.44 % of trials as errors, a very low rate which again confirmed that the task was easy to perform. Total trajectories times exceeding 2 standard deviations from each participant's mean were excluded from the analysis, leading to the removal of additional 8.99 % of the data. The total trimming was of 11.43 % of trials.

As in experiment 1, the remaining data were entered into a 2 × 2 × 2 within subjects ANOVA, with the factors response device (big mouse vs. small mouse), target type (artifact vs. natural) and target dimension (big vs. small). Where possible, interaction effects were evaluated with Newman-Keuls post hoc test ($p < 0.05$).

The ANOVA on initiation times showed the main effect of response device. Indeed, as in experiment 1, the initiation times were longer with the big than with the small mouse (416 and 284 ms, respectively; $F(1, 23) = 21.30$, $\text{MSE} = 39178.9$, $p < 0.001$). No other main effects or interactions were significant.

The analyses on total trajectory times revealed as significant the main effect of target type [$F(1, 23) = 11.58$, $\text{MSE} = 3626.48$, $p < 0.01$], with shorter latencies for natural ($M = 1{,}403$ ms) than artifact ($M = 1{,}433$ ms) items. No other main effects or interactions were significant.

Trajectory spatial analysis

The ANOVA on AUC demonstrated the main effects of the factors response device and target type. An interaction was reliable as well.

The response device main effect showed that, as in experiment 1, the big mouse mean AUC ($M = 0.33$) was smaller than the small mouse mean AUC ($M = 0.52$ ms), $F(1, 23) = 12.05$, $\text{MSE} = 0.1455$, $p < 0.01$. The factor target type, $F(1, 23) = 6.59$, $\text{MSE} = 0.02852$, $p < 0.05$, confirmed also in the AUC results an advantage for natural items ($M = 0.40$) over artifacts ($M = 0.46$).

The three-way interaction between response device, target type × target dimension was significant as well, $F(3, 92) = 4.95$, $\text{MSE} = 0.03456$, $p < 0.05$ (big mouse/artifact: big target $M = 0.37$—small target $M = 0.34$, natural: big target $M = 0.29$—small target $M = 0.33$; small mouse/artifact: big target $M = 0.53$—small target $M = 0.59$, natural: big target $M = 0.54$—small target $M = 0.43$). It showed that for word presentation a subtle compatibility effect was modulated by the target stimulus category; the difference concerned especially the small target when participants were using the small mouse, with artifacts ($M = 0.59$) eliciting significantly higher AUC mean values than natural items ($M = 0.43$) (Newman-Keuls $p < 0.05$) (see Fig. 5).

The ANOVA on MD demonstrated the main effects of the factors response device and target type. An interaction was reliable as well.

The response device main effect was due to the big mouse mean MD ($M = 0.18$) being smaller than the small

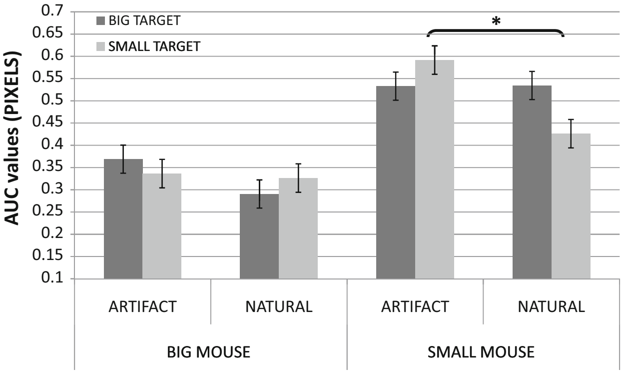

Fig. 5 Experiment 2—interaction response device × target type × target dimension (AUC mean values)

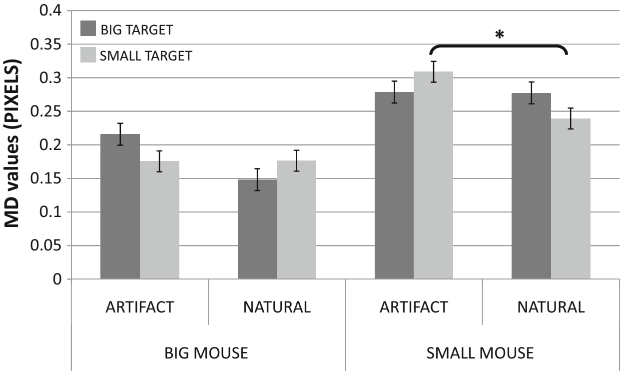

Fig. 6 Experiment 2—interaction response device × target type × target dimension (MD mean values)

mouse mean MD ($M = 0.28$ ms), $F(1, 23) = 11.42$, $MSE = 0.03927$, $p < 0.01$. The factor target type, $F(1, 23) = 8.99$, $MSE = 0.00616$, $p < 0.01$, confirmed again the advantage for natural items ($M = 0.25$) over artifacts ($M = 0.21$).

Finally, the three-way interaction between response device, target type and target dimension was significant too, $F(3, 92) = 5.55$, $MSE = 0.00998$, $p < 0.05$ (big mouse/artifact: big target $M = 0.22$—small target $M = 0.18$, natural: big target $M = 0.15$—small target $M = 0.18$; small mouse/artifact: big target $M = 0.28$—small target $M = 0.31$, natural: big target $M = 0.28$—small target $M = 0.24$), showing a pattern identical to the correspondent interaction in the AUC analysis (see Fig. 6). No other main effects or interactions were significant.

So, in experiment 2, the interaction of the factors response device and target dimension was not significant in the two considered measures, implying a difference for visual and linguistic stimuli, which will be discussed further.

Discussion of experiment 2

In experiment 2, results with words were quite different from those obtained with objects. The continuous recording of participants' mouse movements did not show the predicted compatibility between the hand posture and the implied dimension of the target stimulus. Thus, we failed to replicate with the present paradigm and the present measures the results obtained by Tucker and Ellis (2004), who found a compatibility effect in RTs not only with objects but also with words. However, the absence of the interaction between the factors response device and target dimension in the AUC and MD analyses may not tell the whole story, as indicated by the interaction of response device, target type and target dimension. While using the small mouse, and thus performing a precision grip, there was an inhibition effect on the processing of artificial small targets and facilitation for natural small targets. This result might appear counterintuitive at first sight, because the literature on affordances generally reports facilitation effects in case of congruency of target size and response grip independently on the kind of stimulus presented; however, this evidence was drawn from responses given by single finger key presses (e.g., Borghi et al., 2007; Tucker & Ellis, 1998), or one shot grip execution (Tucker & Ellis, 2004). On the contrary, in our experiment the skilled grip was performed continuously over the device, thus the interference might have been provoked by a preactivation of function-related neural circuits by the skilled grip execution. The fact that these circuits would be already recruited and thus "occupied" would determine a selective inhibition of the processing of artifacts, which are more strongly associated with functional affordances than natural items, especially in the case of linguistic material processing (Borghi, 2012). Interestingly, this interaction also showed that the effect of the category was present only with targets congruent with the grip performed on the device: when participants used the small mouse the big target conditions showed very close AUC and MD mean values (AUC artifact $M = 0.53$, natural $M = 0.54$—Newman-Keuls $p = 0.96$; MD artifact $M = 0.28$, natural $M = 0.28$—Newman-Keuls $p = 0.95$), while when using the big mouse this was true for the small target conditions (AUC artifact $M = 0.34$, natural $M = 0.33$—Newman-Keuls $p = 0.87$; MD artifact $M = 0.18$, natural $M = 0.18$—Newman-Keuls $p = 0.95$). This result might indicate that a fine-grained simulation taking into account action-relevant properties of the target stimulus (i.e., size, category) is activated only when it is possible to plan a meaningful action. Finally, the main effects of the object kind observed in both MD and AUC analyses, due to the higher uncertainty with artifacts compared to natural objects, strictly matched the results of experiment 1.

At first sight, the absence of the predicted compatibility effect might seem problematic for an embodied account of language processing, according to which words are grounded in perception, action and emotional systems (see Barsalou, 2008; Fischer & Zwaan, 2008; Jirak et al., 2010; Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012). However, even if we did not find the same results with words and images, we found evidence of the activation of motor information with words as well. The presence of the effect of size suggests that words indeed elicit modal information as part of an embodied re-enactment or simulation of the associated sensory-motor experience (Barsalou, 2008; Pezzulo et al., 2011; Pezzulo et al., 2013, Pezzulo, Candidi, Dindo, & Barca, 2013).

Our results cannot be accounted either by the classical embodied views or by the propositional view. Rather, they are compatible with the third view we briefly outlined while introducing the experiment. Theories of reuse and motor exploitation suggest indeed that language recruits and reuses structures and mechanisms characterizing the motor system (Anderson, 2010; Pezzulo & Castelfranchi, 2009; Gallese, 2008). However, this is not the end of the story, since language also modifies these structures and mechanisms and builds on them (Borghi, 2012; Gallese, 2008). For example, it has been shown that language recruits only some kinds of affordances, as those linked to stable characteristics of objects, as for example object size and not object orientation (Borghi, 2012; Borghi & Riggio, 2009; Ferri, Riggio, Gallese, & Costantini, 2011; Myachykov, Ellis, Cangelosi, & Fischer, 2013). Our results interestingly indicate that, while the compatibility between the executed grip and the observed visual object occurs online, motor information on object size is processed offline and influences language comprehension.

Conclusions

We reported that static hand postures facilitate compatible responses with objects requiring either a precision or a power grip. Specifically, we demonstrated this investigating the effects of compatible or conflicting information as they were reflected in the trajectories of overt hand movements: participants were instructed to use a mouse to reach for objects or for words referring to objects on the computer screen. To our knowledge the present is the first work that provides evidence of this kind, obtained with kinematic measures.

This evidence clearly favors an embodied account of cognition, according to which observing objects activates the motor system. While object observation leads to the activation of fine-grained motor information aimed at preparing a specific kind of grip, the story is different for words. With words we found indeed evidence of activation of motor information, as the effect of size suggests, but we failed to replicate the compatibility effect previously found by Tucker and Ellis (2004) with a different paradigm. As argued in the discussion of experiment 2, this can be interpreted in the framework of embodied theories of reuse, according to which language recruits some characteristics of the motor system, modifying and building on them.

The comparison of the results obtained with objects and words suggests that the compatibility effects found with objects occur online, thus are likely due to the activation of the dorsal route rather than of the ventral stream (Milner & Goodale, 1995). Further research should explore whether the effects would be similar with words and with not scaled images (i.e., with images that do not allow computing online the object size). Notice indeed that the images we used in experiment 1 were scaled; they maintained some resemblance to the original size, even if larger objects were more reduced in dimension compared to small ones, to fit them within the square.

Less crucial to our main hypothesis but still important for an embodied cognition view is the advantage of artifacts over natural objects. This advantage, which is likely due to the activation (with artifacts) of both manipulation and functional information, is present with both objects and words, thus it is probably not merely due to the dorsal route activation.

Overall our study shows that static hand posture influences the on-line dynamics of a decision even if it is irrelevant to the performance of the task. Unexpectedly, for opponents to an embodied cognition view, the way the mouse is held seems to have a number of effects on human decision processes.

Acknowledgments This research was supported by the EU funded Projects “ROSSI—Emergence of communication in RObots through Sensorimotor and Social Interaction”, contract no. FP7-STREP-216125, and “Goal-Leaders—Goal-directed, Adaptive Builder Robots”, contract no. FP7-STREP-270108. We thank Jon Freeman for his comments on a previous version of the manuscript.

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