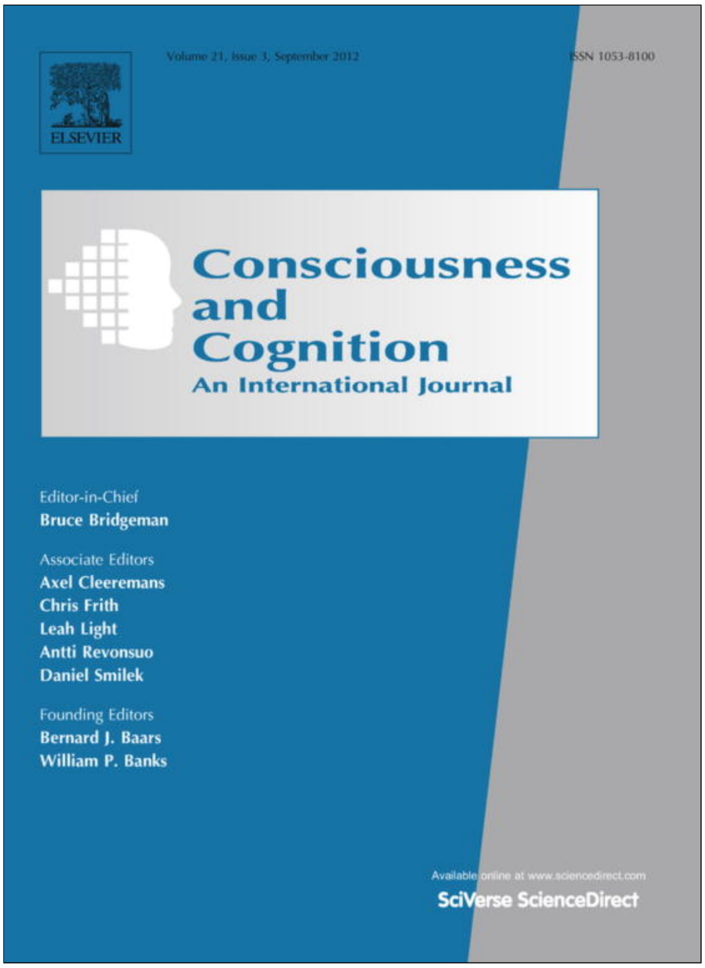
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Short Communication

Which body for embodied cognition? Affordance and language within actual and perceived reaching space

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A B S T R A C T

The mental representation of one's own body does not necessarily correspond to the physical body. For instance, a dissociation between perceived and actual reach-ability has been shown, that is, individuals perceive that they can reach objects that are out of grasp. We presented participants with 3D pictures of objects located at four different distances, namely near-reaching space, actual-reaching space, perceived-reaching space and non-reaching space. Immediately after they were presented with function, manipulation, observation or pointing verbs and were required to judge if the verb was compatible with the object.

Participants were faster with function and manipulation verbs than with observation and pointing verbs. Strikingly, with both function and manipulation verbs participants were faster when objects were presented in actual than the perceived reaching space. These findings suggest that our knowledge of the world is implicitly built online through behaviour, and is not necessarily reflected in explicit estimates or conscious representations.

1. Introduction

According to Gibson (1979), affordances are properties of the environment providing the observer with practical opportunities that he or she is able to perceive and use.

Post-Gibson literature generally assumes that affordances are dispositional properties of the environment that must be complemented by dispositional properties of individuals (Shaw, Turvey, & Mace, 1982; Turvey, 1992). According to the Blackwell dictionary of western philosophy, a dispositional property is the capacity of an object to affect or to be affected by other things. For instance, being graspable is a dispositional property of a handled mug. Recent empirical data (Cardellicchio, Sinigaglia, & Costantini, 2011; Costantini, Ambrosini, Scorolli, & Borghi, 2011; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010; Ferri, Riggio, Gallese, & Costantini, 2011; Yang & Beilock, 2011) have shown that the perception of affordance is modulated by the spatial relation between the object and the agent, that is, it is more efficient when the visually presented object falls within the reaching space of an onlooker endowed with motor abilities which allows him or her to skilfully interact with the object. But what do we really mean when talking about abilities? In this context, abilities are all the motor potentialities an individual is endowed with. To give an example: reach-ability can be construed as a motor potentiality.

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However, a distinction can be made between perceived reach-ability and actual reach-ability. A relatively common finding among studies of perceived estimates vs. actual movement is the observation of an overestimation bias in reach-ability at midline positions (Fischer, 2000; Mark et al., 1997). That is, individuals exhibit a general tendency to perceive that they can reach objects that are out of grasp. Explanations for this overestimation bias in perceived reachability have focused on two possibilities, both based on a misconception of the one's own action capabilities during the motor simulation involved in the reachability estimates. According to the whole body engagement hypothesis (Rochat & Wraga, 1997), this bias depends on the participants' engagement in a simulated reach that includes all degrees of freedom, as in their everyday experience of reaching, whereas they are generally tested in situations that prevent natural body movements. The postural stability hypothesis (Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989) proposes that participants tend naturally to overestimate their reaching range as long as their body's centre of mass will be safely supported during the simulated movements required to contact the object. To date, however, none of the two hypotheses can account for the full pattern of results in reachability judgments (Delevoye-Turrell, Bartolo, & Coello, 2010; Fischer, 2000). Here we took advantage of the naturally occurring differences between perceived reach-ability and actual reach-ability in a sample of right-handed people, to investigate whether the perception of affordances (e.g. the handle of a mug) mainly depends on the individual's perceived reaching space or his/her actual reaching space. Participants were presented with 3D images of objects at four different distances, namely near reaching space (30 cm), actual reaching space (corresponding to each participant's reaching range), perceived reaching space (corresponding to each participant's estimation of her own reaching space) and non-reaching space (140 cm). Immediately after a function, manipulation, pointing or observation verb was presented. Participants had to provide a response if the verb was compatible with the previously observed object, i.e. the verb represented an action which could be performed with the object. Our interest lies in verifying the extent to which verb comprehension, which is thought to be based on a mental simulation process (e.g. Barsalou, 2008), reflects the way in which object affordances are perceived. Specifically, we aim to investigate whether comprehension of verbs referring to actions with objects reflects perceived or actual object reachability. In other words, we intend to verify whether the simulation formed during language comprehension is grounded in the conscious representation of reachable space, or whether it is grounded in the actual reachable space.

Notice that the term simulation is used also to refer to the activation of the motor system induced by observation of objects. Independently of whether we want to use the highly debated term of simulation or not (see Borghi, 2011 for a critique of the term), what counts here is to clarify the relationship between the processes (the "simulation"?) formed while observing objects and while comprehending words referring to objects. A number of behavioural and neural studies have shown that observation of objects, and particularly of tools, induces the preparation of motor actions (e.g. Tucker & Ellis, 2004; for a review on neural evidence see Martin, 2007), possibly through the mediation of the canonical neuron system (Rizzolatti & Craighero, 2004). Given that, according to embodied theories, language is grounded in perception and action system, the same tendency to prepare an action would be evoked when pronouncing, listening or reading the word corresponding to an object on which to act (e.g. Barsalou, 2008; Gallese, 2008). For this reasons many authors favouring an embodied cognition approach use in both cases the term simulation.

A variety of behavioural, brain imaging and neurophysiological studies have provided evidence that the simulation formed is rather detailed and sensitive to the different effectors implied by the sentence, to the action perspective, etc. (Barsalou, 2008; Chersi, Thill, Ziemke, & Borghi, 2010; Fischer & Zwaan, 2008; Toni, de Lange, Noordzij, & Hagoort, 2008). However, it has yet to be investigated whether the simulation built reflects the real dynamics of the actions, or whether it simply reflects the way we explicitly represent action. Our paradigm allows us to test precisely this.

If during language comprehension a simulation is built that is sensitive to object affordances and to their location with respect to the agent's body, then responses to action verbs (i.e., manipulation and function ones) should be modulated by object spatial location. Specifically, they should be faster with objects located in the peripersonal than in the extrapersonal space; this difference should not be present for observation and pointing verbs. This result would confirm the one found by Costantini, Ambrosini, Scorolli & Borghi, (2011) and extend it to pointing verbs. In addition, if the simulation built during language comprehension reflects the real dynamics of actions, then we predict that responses to action verbs should be faster when primed by objects located within the actual and not the represented reaching space. If it reflects the way actions are represented, then they should be faster with objects located within the estimated reaching space.

2. Methods

2.1. Participants

Fifteen healthy subjects (8 males, mean age 25.5 years) participated in the experiment. All participants were native Italian speakers, had normal or corrected-to-normal visual acuity and were right-handed according to self report. Participants were naïve to the hypotheses under investigation and gave their informed consent.

2.2. Materials

The experimental stimuli were images and verbs. Seven *Manipulation* Verb – *Function* Verb – Object triads were selected from our previous work (Costantini, Ambrosini, Scorolli & Borghi, 2011), in an attempt to match each object with a highly compatible manipulation and function verb. Due to the difficulty in pinpointing a large variety of *Observation* and *Pointing* verbs, we used only four and two distinct verbs of this kind. As a result, verb stimuli consisted of four lists of Italian verbs in the imperative form referring respectively to *Function*, *Manipulation*, *Pointing* and *Observation* (see Appendix). Also, the frequency of use (DeMauro, Mancini, Vedovelli, & Voghera, 1993) was checked for each verb and we found the following: Function = 6.42; Manipulation = 26.28; Observation = 98 and Pointing = 15.50.

Image stimuli consisted of colour images (1024 × 768 pixels) of a 3D virtual room created by means of 3D Studio Max™, a software of virtual reality which allows one to create real-world scaled images. Each picture depicted a table with an object placed on top of it. Seven common objects were used, and all were presented with their handle or graspable part oriented towards the right. The objects were presented at four different distances, with the closest and the most distant of them fixed at 30 and 140 cm, respectively. The two intermediate distances varied for each subject and corresponded to his or her actual and perceived maximum reach range (see Section 2.3; Fig 1).

In order to alleviate the possible misperception of absolute distances in the virtual environment (Durgin, Fox, Lewis, & Walley, 2002; Mohler, Creem-Regehr, & Thompson, 2006; Richardson & Waller, 2007; Sahm, Creem-Regehr, Thompson, & Willemsen, 2005), we used a geometric field of view value (≈75 horizontal degrees) that permits an accurate perception of distances in virtual environments (Waller, 1999), and the eyepoints (i.e., the centre of perspective projection) were located at about the eye level of a human seated on a chair. Moreover, similar stimuli have been used in previous works from our group (Cardellicchio, Sinigaglia, & Costantini, 2012; Cardellicchio et al., 2011; Costantini, Ambrosini, Scorolli & Borghi, 2011; Costantini, Ambrosini, Sinigaglia, & Gallese, 2011; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010; Costantini, Committeri, & Sinigaglia, 2011), and we found an high accuracy in the participants' explicit judgments of the metric distance at which the virtual objects were presented.

As expected, participants systematically perceived their grasping space to be larger and out of their potential range. In fact, participants estimated their reaching limit to be 71.5 cm, whereas the actual reach span was 61 cm (two-tailed t-test: $t(28) = 4.98$; $p < .001$).

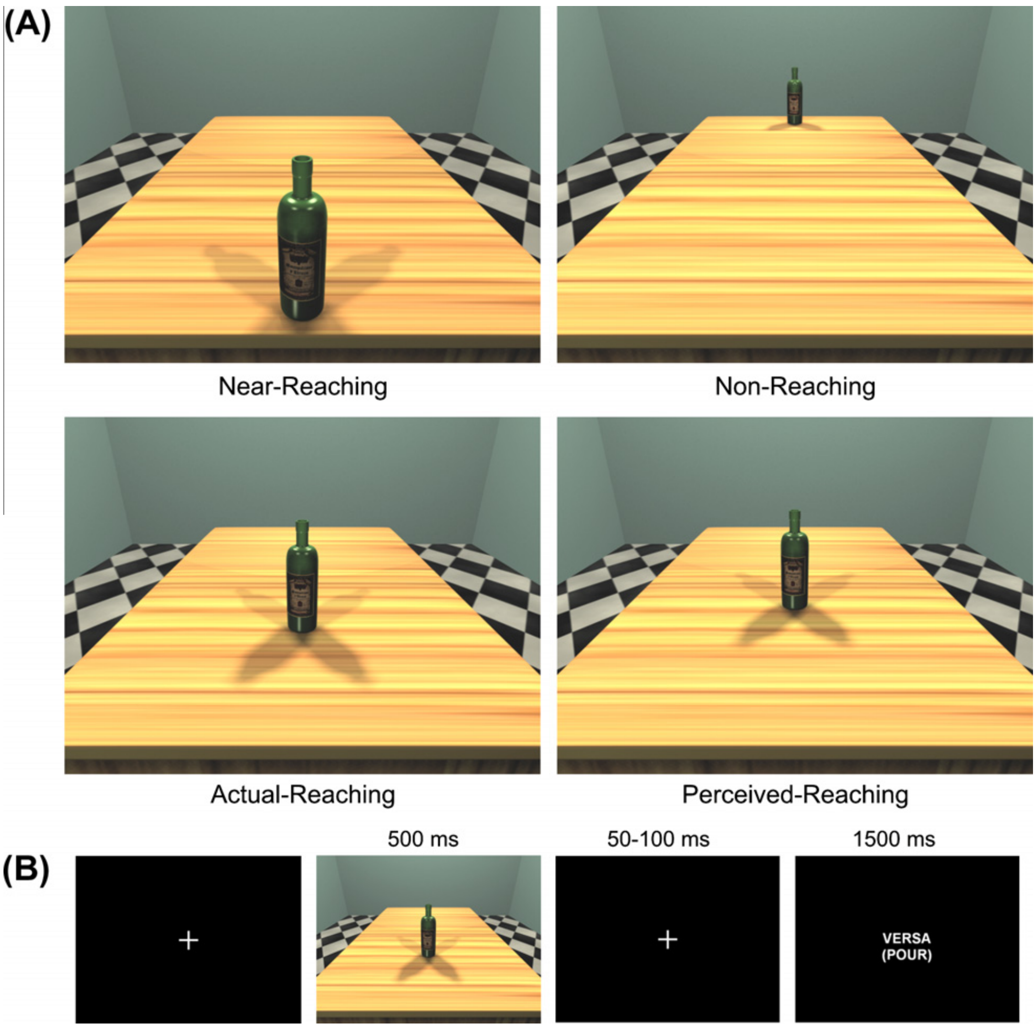

Fig. 1. Example of experimental stimuli. Colour images of a 3D virtual room were used, allowing to present the objects either within the reaching (near and actual) or non-reaching (perceived and far) spaces (Panel A). Experimental timing (Panel B). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3. Procedure

Before the experimental task we conducted a preliminary session in order to collect the perceived and actual maximum reach distance for each subject. Participants were seated on a chair at a uniformly white table. The distance from the subject's eye to the table border was 25 cm, in order to maintain the same perspective as the visual stimuli. The experimenter moved an object (a no-handled mug) at a slow speed of about 2 cm/s away from or toward the participant. Subjects were instructed to say "stop" when they thought they could barely grasp it with the right arm without moving their shoulders from the back of the chair. The experimenter then stopped moving the object and used a tape measure to determine the distance between the participant's eye and the object. The average of these two measures was approximated at the nearest even centimetre and is here referred to as the perceived reaching space. There was no practice session, and subjects were not allowed to try out their reaching ranges on the table surface.

After the estimation, participants moved onto a different table and their actual reach range was assessed by asking them to place the object as far as they could without leaning forward (hereafter: actual reaching space).

During the experimental session stimuli were presented on a 17″ LCD monitor from a viewing distance of 57 cm. Each trial consisted of the presentation of an object for 500 ms followed, after a delay of 50 or 100 ms, by a verb presented at the centre of the screen lasting 1500 ms. Subjects were requested to respond, if the object–verb combination was appropriate (e.g. ball-to play), and to refrain from responding if the object–verb combination did not make sense (*Catch trials: ball-to pour*). For every object, all four types of verbs were presented twice in each of the four distances, resulting in 14 trials per condition, for a total of 224 trials plus 56 catch trials (20%). Participants provided the response by lifting the right index finger from a response button and then mimicking a reach-to-grasp movement toward the computer screen. This allowed us to measure liftoff time (i.e., the time between onset of the verb stimulus and initial hand movement).

3. Results

Trials in which participants failed to respond (errors: 0.5%) or provided a response when it was not required (false alarms 0.6%) were excluded from the response times (RTs) analysis. The mean RTs were calculated for each condition; responses more than 2 standard deviations from the individual mean were treated as outliers (4.4%). Data were entered in a two-way ANOVA with Object Location (Near-Reaching vs. Actual-Reaching vs. Perceived-Reaching vs. Non-Reaching space) and Verb (*Function* vs. *Manipulation* vs. *Pointing* vs. *Observation*) as within-subjects factors. Whenever appropriate, post hoc comparisons were performed with the Newman–Keuls method. An alpha level of 0.05 was always used.

The analysis revealed a significant main effect of Object Location ($F_{(3,42)} = 7.35$; $p < .001$; $\eta_p^2 = 0.34$). Post-hoc analysis showed faster RTs for both Near-Reaching ($M = 683$ ms) and Actual-Reaching space ($M = 676$ ms) compared to those in both Perceived-Reaching ($M = 709$ ms) and Non-Reaching space ($M = 715$ ms). The ANOVA also revealed a significant main effect of Verb ($F_{(3,42)} = 23.43$; $p < .0001$; $\eta_p^2 = 0.63$). Post-hoc analysis revealed that both RTs for Function and Manipulation trials ($M = 653$ and 675 ms, respectively) were faster than both RTs for Pointing and Observation trials ($M = 718$ and 738 ms, respectively; $ps < .05$), which in turn did not differ from each other. Moreover, the difference in RTs between Function and Manipulation trials approached significance ($p = .053$). The most important result, however, was the significant interaction between Object Location and Verb ($F_{(9,126)} = 2.18$; $p = .027$; $\eta_p^2 = 0.13$). This interaction is illustrated in Fig. 2 and shows that on Function Trials, RTs were faster when the object was presented in both reaching spaces ($M = 628$ and 620 ms for Near-Reaching and Actual-Reaching space, respectively) compared to both non-reaching spaces ($M = 671$ and 692 ms for Perceived-Reaching and Non-Reaching space, respectively; $ps < .05$). The same RTs pattern was observed for Manipulation trials ($M = 649$, 656, 694 and 702 ms for Near-Reaching, Actual-Reaching, Perceived-Reaching and Non-Reaching space, respectively, with the first two that were significantly lower than the last two: $ps < .05$), whereas there were no significant differences between RTs for objects presented at different locations for Pointing or Observation trials (all $ps > .1$).

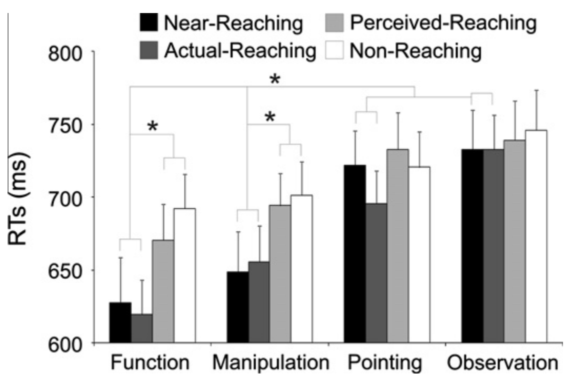

Fig. 2. Mean reaction times in the experimental conditions. Error bars indicate standard errors. * indicates $p < .05$.

4. Discussion

Previous studies warn that the claim that affordances are automatically activated should be viewed with caution. Both theoretical and empirical evidence has been provided, supporting the idea that the perception of affordances is context-dependent and spatially-constrained (Cardellicchio et al., 2011; Cermolacce, Naudin, & Parnas, 2007; Chemero, 2003; Costantini, Ambrosini, Scorolli & Borghi, 2011; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010; Costantini, Committeri, & Sinigaglia, 2011; Costantini & Sinigaglia, 2012). This suggests that we experience objects as graspable, provided that they fall within our reaching space, i.e. when an actual interaction is possible.

Here, we presented participants with 3D objects at four different distances, namely near reaching space, actual reaching space, perceived reaching space and non-reaching space. We found that participants were faster at responding to manipulation and function verbs that were primed by objects presented within the actual rather than the estimated reaching space.

To us, our results have interesting theoretical implications not only for literature on affordances, but more generally, for literature on perceptual awareness. According to Proffitt (2006), visual perception of the physical world is not simply a function of optically specified objective features of the environment, but is constrained by the perceiver's capacity to act on that given space, at a given time. For instance, in a recent study Schnall, Zadra, and Proffitt (2010) investigated whether and to what extent perceptual estimates about a steep hill were impacted by participants' levels of blood glucose, the primary fuel for muscle contraction. They asked two groups of subjects to consume a blackcurrant-flavoured juice drink containing glucose or the same juice, but containing non-caloric sweetener, respectively. They found that participants who drank juice containing sugar estimated the hill to be less steep than did participants who drank juice containing non-caloric sweetener. In the same vein, Bhalla and Proffitt (1999) employed the same task (perceptual estimates about a steep hill) when people were encumbered by wearing a heavy backpack, fatigued after a long run, of low physical fitness, or elderly or in poor health. They found that slant judgements were increased by the reduction in physiological potential brought about by all of the above experimental manipulations. This evidence and our results support this notion, showing a significant role of actual functional capabilities of one's body in the conscious awareness of the physical world. Indeed, in our case an object suggests an action only when it falls within the actual reaching space of the perceiver.

Moreover, our results illustrate that both observation and pointing verbs differed from manipulation and function verbs, and that observation and pointing verbs were not modulated by the object spatial location. This suggests that what makes the difference between the reachable vs. non-reachable space is the possibility of interacting with objects in a physical and realistic way. Our finding does not support explanations that suggest that pointing is a form of failed grasping (for a similar position: Leavens & Hopkins, 1999). Studies with infants are in line with this idea and (Franco & Butterworth, 1996) show that, while reaching is only produced in an imperative-instrumental context, pointing is characteristic of declarative-referential contexts. In addition, it fits with some data showing that pointing has a ventral representation (Weiss et al., 2000), similar to perceptual judgements. Alternatively, it is possible that our results only captured the differences between the two gestures that develop later, once new reference frames are computed for grasping. This interpretation is plausible, since we did not present real actions but verbs referring to actions. Moreover, it would be compatible with the idea of pointing as failed grasping, and would account for the similarity of the neural networks involved in pointing and grasping (Grafton, Arbib, Fadiga, & Rizzolatti, 1996), and for the evidence (e.g. Edwards & Humphreys, 1999) showing that pointing and grasping do not differ in the early reaching phases.

Possibly, one may argue that the differential effect we found between the four kind of verbs could be accounted for by the experimental design, that is, each observation and pointing verb was presented more frequently during the experiment compared to each manipulation and function verb. Moreover, there were no catch trials with observation and pointing verbs, so they were always responded to. However, our results contrast a frequency based account: indeed, observation and pointing verbs were responded to more slowly than both manipulation and function verbs. Most importantly, consider that our task required participants to respond only if the object–verb combination was appropriate (catch trials were only 20%), and that we did not use different blocks for each kind of verb. Due to the mixed design we used it would be improbable that participants formed separate categories for each verb kind (Observation, Pointing, Function and Manipulation) and decided to respond to Observation and Pointing ones, but not to the other verbs. To accomplish the task it is much more probable that they simply responded to the sensibility of each combination.

Also, it can be hypothesised that the effect we found was merely due to attentional factors, indeed it is known that objects presented below the eye level are attended to sooner than those above eye level (Shelton, Bowers, & Heilman, 1990). However, if it was the case we should have found faster reaction times to objects presented in the reachable space as compared to those presented in the non-reachable space, regardless of the kind of verb associated with the object.

An alternative explanation of our results can pertain the specificity of the verb in each object–verb combination. One could argue that, while observation and pointing verbs are rather unspecific as they can be combined with all objects, manipulation verbs are less specific and function verbs are most specific with regard to the selected objects. Although we cannot rule out this possibility it should be reminded here that our main interest relies in the modulation produced by spatial location of the object within each verb category rather than across verb categories. Moreover, the difference we found between manipulation and function verbs is in line with previous studies. For instance, literature on categorisation shows that even in 2-year-olds artifacts are characterised by functional information (e.g. Kemler Nelson, Russell, Duke, & Jones, 2000). Furthermore, other evidence indicates that language has a privileged relationship with function, rather than with manipulation: Masson, Bub, and Newton-Taylor (2008) demonstrated that sentences not related to any form of manual interaction primed functional but not manipulation gestures.

Compared to other studies, our result is particularly striking for a variety of reasons. First, we found a major role of the actual reaching ability in an offline task that did not require direct interaction with objects, but only evoked a simulated action. Even if the task required matching a verb with an image of an object, without interacting with it, participants' performance did not reflect the reaching ability estimated in a previous offline task; instead, it reflected the actual reaching ability, recorded online. Second, the difference between the kinds of interactions with objects (manipulation and function vs. pointing and observation) was found in a task that utilised linguistic stimuli. Notice that the fact that the performance reflected the actual reaching ability contributes to rule out the idea according to which the involvement of the motor system is not constitutive for language comprehension but is an a posteriori occurring process (Mahon & Caramazza, 2008).

We believe our findings have wide implications for literature on language comprehension. Our results strongly support embodied and grounded views (Borghi & Pecher, 2011) according to which action verbs lead to the activation of the same perceptual and motor system recruited while performing those actions (Borghi & Scorolli, 2009; Buccino et al., 2005; Costantini, Committeri, & Galati, 2008; Ferri et al., 2012; Gallese, 2008; Marino, Gallese, Buccino, & Riggio, 2010; Pecher, van Dantzig, Zwaan, & Zeelenberg, 2009; Pulvermuller, 2005; Scorolli & Borghi, 2007). This is not the whole story, though. Our results are the first to suggest, with a novel behavioural method, that the simulation formed during verb comprehension is very precise and detailed, as it reflects the real interrelations between our body and the seen object, not the way in which we explicitly represent (and overestimate) our bodily capabilities.

These results can also be also interpreted in the light of the enactive view of perception. Enaction is the idea that organisms create their own experience through their actions. Organisms are not passive receivers of input from the environment, but are actors in the environment such that what they experience is shaped by how they act. As Varela puts it: "the enactive approach underpins the importance of two interrelated points: (1) perception consists of perceptually guided action and (2) cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided" (Varela, Thompson, & Rosch, 1991). Similarly, Noë (2004) says that perception is something we do, not something that happens to us.

The framework emerging from our experiment suggests that our knowledge of the world is built online, via current information, implicitly through behaviour, and is not necessarily reflected in explicit estimates or conscious representations. We believe this has interesting implications for theories of cognition, as it helps us to better qualify the notion of objects and of body/embodiment (for discussions on this issue, see Borghi & Cimatti, 2010). In the view we are endorsing, an object encompasses the actions you can effectively perform with the object in question, not only in principle, and independently of the current context.

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Appendix A

	Verbs			
Objects	Function	Manipulation	Pointing	Observation
Ball	Gioca (to play)	Colpisci (to hit)	Indica (to point)	Osserva (to watch)
Bottle	Versa (to pour)	Tappa (to plug up)	Indica (to point)	Guarda (to look)
Controller	Premi (to push)	Appoggia (to put)	Indica (to point)	Vedi (to see)
Hammer	Batti (to hammer)	Impugna (to clasp)	Punta (to point)	Fissa (to gaze)
Mug	Bevi (to drink)	Prendi (to bring)	Punta (to point)	Vedi (to see)
Pan	Cucina (to cook)	Lava (to wash)	Indica (to point)	Osserva (to look)
Shovel	Scava (to dig)	Afferra (to grasp)	Punta (to point)	Guarda (to watch)

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