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ARTICLE

Attentionally modulated motor-to-semantic priming: evidence from a property verification task

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Abstract
Previous research has shown that motor information influences visual and semantic tasks. However, not much is known about the specific influence of structural, action-relevant information on language processing. In the current study, participants were instructed to observe a prime graspable object (e.g., a frying pan) that could be presented with the action-relevant component (that is its handle) oriented either toward the left or toward the right. Subsequently, they performed a property verification task on a following target word, which could describe an action-relevant (e.g., handle) or action-irrelevant (e.g., ceramic) characteristic of the just-encountered object. They were required to make a keypress response with either a key on the same side as the depicted action-relevant component of the prime object (that is compatible key) or on the opposite side (that is incompatible key). Results show that property verification judgements for action-relevant words were faster in the spatially compatible condition than in the spatially incompatible condition, whereas judgements for action-irrelevant target words were not affected by spatial compatibility. These findings suggest that spatialized object properties are not mandatorily linked to manual response biases. Rather, this link seems to be modulated by trial-by-trial changes in conceptual focus.

Keywords: action-relevant information; affordance; language processing; priming paradigm; property verification; semantic system

Information about how an object can be manipulated is invaluable for human beings. We grasp, carry, lift, strike, push, pull, throw and hold objects, to mention just a few manual actions.

Knowledge about human–object interaction consists of functional and structural (or volumetric) information. Functional knowledge refers to understanding how objects can be manipulated to make them work, such as knowing that the remote control must be pointed toward the TV to operate it. Structural knowledge, in contrast, refers to properties concerning an object's structure and the spatial locations of its parts, such as a pan's handle orientation. Gibson (1979) referred to these structural properties as affordances of objects.

Research has shown that knowledge about how objects can be manipulated affects tasks that themselves do not require object manipulation, including linguistic tasks. The question remains, however, whether structural affordances specifically influence verbal processing, which is the focus of the current study.

1. Functional knowledge in cognitive processing

Several studies have demonstrated that functional knowledge about objects influences cognitive tasks. Indeed, in a word-to-picture matching task, Campanella and Shallice (2011) observed that participants were slower at identifying a target object (e.g., pincers) that was previously verbally primed if it was shown along with a distractor object sharing a similar manipulation (e.g., nutcracker) rather than an object with a similar visual appearance (e.g., compasses). Furthermore, they also found that performance worsened across presentations if the pair of distractor–target objects shared a similar manipulation, whereas it improved if the pair of objects shared a similar visual appearance.

In addition, Helbig et al. (2006) found better naming accuracies in a picture-to-picture naming task if the prime and target manipulable objects involved similar (e.g., pincers-nutcracker) rather than dissimilar (e.g., pincers-horseshoe) actions (see also Helbig et al., 2010 for a similar result using a video clip of functional gestures rather than pictures of static objects). Therefore, both interference and facilitation effects due to the activation of functional information have been observed, with interference occurring in visual tasks and facilitation with naming.

Further evidence comes from Myung et al. (2006) who demonstrated that adults are faster to perform lexical decisions on target words if they are previously primed with semantically dissimilar words that involve the same manipulating body part (e.g., *typewriter-piano* as connected via hands as manipulators). These studies argue in favor of strongly interacting language and sensory motor systems in the human brain (Goldstone & Barsalou, 1998) and collectively suggest that functional information about objects influences cognitive processing across various domains.

2. Dissociating functional from structural knowledge

Importantly, research indicates that functional and structural knowledge may be processed differently in cognitive tasks.

Lee et al. (2013) examined how structural and functional information affects object recognition using eye-tracking. In their sentence-to-picture matching task, participants heard sentences and had to identify the target object from an array that

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included distractor objects. These distractors either shared structural features (requiring similar grip like staplers and hammers) or functional features (serving similar purposes like key fobs and remote controls) with the target. Their findings showed that only sentences conveying functional information made target identification easier.

Similarly, Bub et al. (2008) briefly presented object names as primes followed by photographs of hand postures cueing either a functional or volumetric gesture. Half of the gestures of each type were related to the primed object name. Participants responded by performing the cued gesture on a Graspasaurus (i.e., a response apparatus designed to afford a specific manual gesture) and by classifying the prime as a word or nonword. Crucially, only hand responses corresponding to the function of the object were facilitated when object names were presented as primes. Such findings seem to argue for a primacy of functional over structural knowledge in the representation of lexical concepts (Bub & Masson, 2012).

However, De Bellis et al. (2016) revealed a more complex picture. In their study, people were presented with a picture of either a functional or structural static grasping action, followed by tasks requiring them to judge function similarity between objects (e.g., electric and straight razors versus electric razor and pc mouse; experiments 1 and 3). They found that a functional primed action facilitated judging function when tools had different structural configurations (e.g., electric and straight razors; experiment 1), whereas performance was impaired when tools shared the same structural configuration (e.g., electric razor and torch; experiment 3). This finding suggests that structural knowledge does not just exist alongside functional knowledge but may actively modulate its effects.

Furthermore, studies on the time course of language priming effects on motor activation have shown that while functional actions associated with an object are primed throughout the duration of its name enunciation, volumetric action priming is rapid and abbreviated with auditory word primes (Bub & Masson, 2012; see also Bub et al., 2018 for similar results with visual word primes).

This dissociation is further supported by Garcea and Mahon (2012) who demonstrated that knowledge of object function and knowledge of object manipulation correspond to dissociable types of object knowledge: While they found that the activation of motor information is not necessary for retrieving knowledge of object function, they found that motor information does play a role in accessing object's structural knowledge.

3. Structural knowledge in cognitive processing

Importantly, there is evidence showing how structural affordances of objects influence motor responses in nonlinguistic tasks. These studies consistently show facilitation when the responding hand of the participant and the orientation of the object's graspable component, that is, its affordance (e.g., the handle) are compatible (i.e., on the same side) rather than incompatible (i.e., on opposite sides) (Tucker & Ellis, 1998; see also Iani et al., 2011; 2019; Scerrati et al., 2020a; 2020b; 2023 for more recent evidence; see Vainio & Ellis, 2020 for a review).

Two competing accounts have been proposed to explain these compatibility effects. According to the *spatial origin explanation*, motor affordances operate as spatial features that capture attention, facilitating responses when their position

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aligns with the response side and interfering when they are misaligned (Chong & Proctor, 2020). Alternatively, according to the *motor-based explanation*, motor affordances trigger specific motor activation patterns across action-based brain networks, which automatically begin preparing the most appropriate limb for potential interaction with the object (Ellis, 2018).

While these compatibility effects are well established in motor response tasks, evidence regarding the influence of structural affordances on linguistic processing remains limited.

A step in this direction was taken by Chrysikou et al. (2017) who examined the influence of motor experience on object knowledge. Their study involved healthy individuals and unilateral stroke patients who were asked to orally determine the type of grasp (i.e., clench or pinch) they would adopt on seeing different types of objects with the handles oriented either toward their left or right hand. Results showed that right-handed healthy participants were faster at determining appropriate grasps when objects were oriented toward their right hand, while patients who had lost the use of their right hand were faster when objects were oriented toward their left hand, indicating that manual handling experience influences the knowledge people store and retrieve about graspable objects. This suggests an influence of structural information on conceptual processing. However, as Murphy (2004) notes, while conceptual and linguistic processing share important features, they are not identical processes. The specific question of how structural affordances affect verbal processing, therefore, represents a significant gap in the literature that the current study aims to address.

4. The current study

The present study was designed to specifically address the open question of whether structural affordances influence the verbal processing of object properties relevant for action. To this end, we used a picture-word priming paradigm. The prime images were pictures of common objects (i.e., can, door, frying pan, radiator) that ensured the availability of structural information and conveyed the spatial location of the object's affordance (e.g., the handle's orientation). Importantly, it has been shown that passively observing tools suffices to elicit action-related representations (e.g., Grafton et al., 1997). The target word could refer to an action-relevant or an action-irrelevant property of the prime object (e.g., *handle*/*ceramic*). Participants were instructed to observe the prime graspable object (e.g., a frying pan) that could be presented with the action-relevant component (that is its handle) oriented either toward the left or toward the right. Subsequently, they performed a property verification task (e.g., Scerrati et al., 2017) on the target word, indicating whether the target word referred to a property of the immediately preceding object. They were required to make a keypress response with either a key on the same side as the depicted action-relevant component of the prime object (that is compatible key) or on the opposite side (that is incompatible key). Filler words were also included. They could describe either things unrelated to the prime object (unrelated words, e.g., *eyelash*) or things thematically associated with the prime object, which, however, were not their properties (i.e., they were not part of the prime object; thematic words, e.g., *lid*).

The two competing explanations for compatibility effects with graspable objects mentioned earlier guided our hypotheses. Under the assumptions of the *spatial origin*

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explanation, we should observe a compatibility effect regardless of the type of target presented to participants given that the salient visual affordances of the objects would capture their attention regardless of whether they are followed by action-relevant or -irrelevant target words. The ensuing compatibility effect could be assimilated to other stimulus–response (S-R) compatibility effects such as the Simon effect (Simon, 1990; see Scerrati et al., 2017), being that it is a kind of object-based Simon effect (see Chong & Proctor, 2020 for reviews).

However, if the motor affordances of objects reflect a specific pattern of activation across action-based brain networks as assumed by the *motor-based explanation*, then we should observe a facilitation on the property verification task if and only if the target word is action relevant (e.g., handle) and the orientation of the action-relevant component of the prime object is spatially compatible with the response key. That is, reading the target word "handle" would lead participants to maintain or pull up an image in their mind of the immediately preceding prime object that was shown. As they inspect this image, they are emphasizing object parts corresponding to the target word. The motor affordance corresponding to the target word (e.g., the handle to the left) will therefore be salient, and an affordance-response compatibility effect is expected. If the target is, instead, "ceramic," then the motor affordance will not be emphasized nor will its spatial position. Accordingly, a position-response compatibility will be weaker or nonexistent in this case. We will refer to this specific account within the *motor-based explanation* as the *word origin account.*

According to this *word origin account* of the compatibility effect, it is predicted that the presentation of the graspable prime object will pre-activate structural information about objects. This, in turn, should facilitate processing words referring to action-relevant properties of object concepts, whereas it should neither facilitate nor hamper processing words referring to action-irrelevant properties of the prime object. Thus, we expect that motor information evoked by object observation will have different effects as a function of the following type of word. Specifically, it is predicted that motor information will determine a motor-to-semantic priming effect for action-relevant words as the processing of these words will benefit from the activation of motor knowledge. Conversely, neither benefits nor disadvantages for action-irrelevant words are predicted as these words refer to motor-irrelevant features of the prime objects. Hence, we expect to observe an interaction between spatial compatibility and the type of object property that is probed.

5. Method

5.1. Participants

We calculated the sample size required to achieve at least 90% power to detect a significant interaction between target word (relevant for action, irrelevant for action) and spatial compatibility (compatible, incompatible) with the G*power 3.1 (Faul et al., 2007) software. With an effect size $f = 0.1758631$ (obtained from a medium $n_p^2 = 0.03$), the power calculation recommended a sample size of at least 59 participants.

Sixty-one participants (44 females; mean age: 23 years old; SD: 3 years) took part in the experiment. All participants were Italian native speakers, had normal or corrected to normal vision and were naïve as to the purpose of the experiment. Handedness was measured by the Edinburgh Handedness Inventory (Oldfield, 1971), which revealed that 50 participants were right handed (laterality mean = 0.75; SD = 0.15), 10 participants were ambidextrous (laterality mean = 0.40; SD = 0.09) and 1 participant was left handed (laterality mean = −0.78).

5.2. Materials

The prime stimuli were digital photographs of four different domestic objects (can, door, frying pan, radiator) selected from public domain images available on the Internet. Prime objects could be presented in two different orientations, with the action-relevant component (e.g., the frying pan's handle) oriented either toward the left or toward the right. These objects subtended a maximum of 13.7° of visual angle horizontally and 12.3° of visual angle vertically when viewed from a distance of 60 cm. Prime objects were centered on the screen according to the length and width of the entire object.

The target stimuli were 8 words belonging to two different categories: Four words referred to a characteristic of the prime object that was relevant for action (e.g., *handle*); four words referred to a characteristic of the prime object that was irrelevant for action (e.g., *ceramic*). For the complete list of stimuli, see the Supplementary Materials. Target words ranged from 2.7 to 5.4 cm (from 5 to 10 characters) which resulted in a visual angle range between 2.5° and 5.1° when viewed from a distance of 60 cm.

Words from the two categories (action relevant, action irrelevant) were matched in terms of frequency and length. For lexical frequency, the Italian database CoLFIS was used (Bertinetto et al., 1995). Values for frequency and length for target words are reported in Table 1.

To control for association strength between the prime object and the target word, 40 additional participants (23 males; mean age: 28 years old; SD: 9 years) who did not participate in the main experiment were asked to rate the eight target words in terms of their degree of association with the prime objects on a 1-to-7-point Likert scale (1 = "not associated at all"; 7 = "very associated"). The mean ratings were 5.2 for action-relevant words and 5.4 for action-irrelevant words related to the prime object and did not statistically differ, $t(39) = -1.31$, $p = .197$.

Eight additional filler words were used in the experiment. These fillers conveyed a property that was always false of the prime objects. Four filler words referred to things unrelated to the prime object (e.g., *eyelash*), whereas the remaining four words referred to things thematically associated with the prime object, which, however, were not their properties (i.e., they were not part of the prime object; e.g., *lid*). This last category of fillers was included in order to increase the depth of processing of target words (Solomon & Barsalou, 2004). Indeed, it has been shown that when prime–target pairs are unrelated (e.g., frying pan-*eyelash*), conceptual representations are not retrieved and subjects likely perform the property verification task on relatively

Table 1. Psycholinguistic matched variables of the target words used in the experiment (p values refer to differences between action-relevant vs -irrelevant words)

	Action-relevant words			Action-irrelevant words			
	Mean	SD	Range	Mean	SD	Range	p value
Frequency	7.7	3.7	3–12	21.2	11.5	11–34	0.09
Length	7.7	1.2	6–9	8	2.1	5–10	0.84

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superficial, association-based processing of word stimuli (Glaser, 1992; James, 1975; McCloskey & Glucksberg, 1979; Smith et al., 1974). In contrast, if some prime–target pairs are also associated on false trials, then a superficial word association strategy is hindered, and conceptual representations must be retrieved to respond correctly.

5.3. Apparatus

Stimulus presentation, response times (RTs) and accuracy were controlled and recorded by E-Prime 2 (Psychology Software Tools, Inc., Sharpsburg, PA). Participants completed the experiment on an HP ProDesk 490 G1 MT running Windows 7 with a 19 *in* monitor and a display with a resolution of 1280 × 1024 pixels.

5.4. Design and Procedure

Two factors were manipulated: *Target word* with 2 levels (action relevant; action irrelevant) and *Spatial compatibility* – between the orientation of the action-relevant component of the prime object and the response – with two levels (spatially compatible: both handle and response on the right or both on the left; spatially incompatible: handle on the right and response on the left or *vice versa*). Both factors were manipulated within subjects.

Participants sat at a viewing distance of about 60 cm from the monitor in a dimly lit room. Each trial started with the presentation of a fixation cross (0.3 cm × 0.3 cm) for 500 ms. Immediately after the fixation, the prime object appeared on screen for 1000 ms. Then, either the target word or the filler word was displayed on the screen until a response was given or until 1500 ms had elapsed (see Figure 1 for details). A response was followed by the message “Correct,” “Incorrect,” or “Too slow,” which appeared for 1000 ms, depending on the response accuracy. RT latencies were measured from the onset of the target stimulus. Both target and filler stimuli were bold lowercase Courier new 18 and were presented in black in the center of a white background.

Participants were asked to make a property verification judgment, that is, determine whether the word described a characteristic of the prime object by pressing one

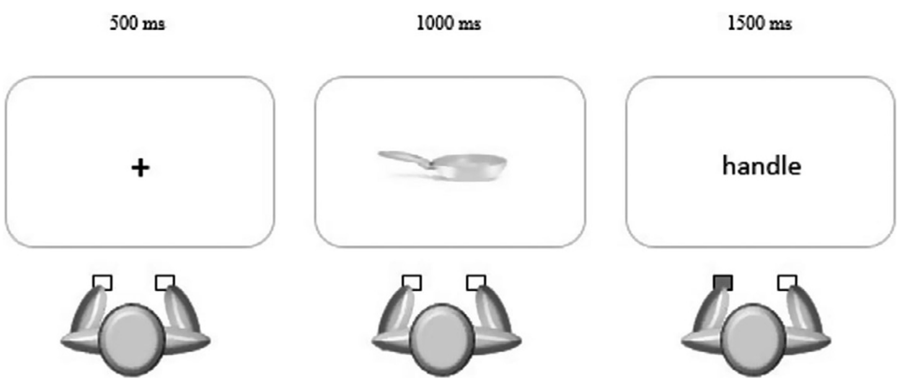

Figure 1. Illustration of an action-relevant target word in the spatially compatible condition. In the example above, the instructions were to respond with the left index finger to target words and with the right index finger to filler words. Note that elements are not drawn to scale.

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of two lateralized buttons as quickly and accurately as possible. Response keys were the "-" and the "z" keys on an Italian QWERTY keyboard. Half of the participants responded by pressing the "-" key with their right index finger when the word described a property of the prime object (e.g., either *handle* or *ceramic* for "frying pan"), and the "z" key with their left index finger when the word described either a property unrelated to the prime object (e.g., *eyelash* for "frying pan") or a prime object's thematically associated property, which, however, was not a property of the object itself (e.g., *lid* for "frying pan"). The other half of the participants were assigned to the opposite mapping.

The order of presentation of each prime object–target word pair was randomized across participants. The experiment consisted of 16 practice trials (different from those used in the experiment) and 2 experimental blocks of 128 trials each for a total of 272 trials per participant. Blocks were separated by a self-paced interval, and the experiment lasted approximately 20 minutes.

5.5. Statistical analyses

The data were analyzed using IBM SPSS Statistics 25. Two repeated measures analysis of variances (ANOVAs) were conducted with target word (action relevant, action irrelevant) and spatial compatibility (compatible, incompatible) as within-subject factors, one for response times (RT) and one for percentage errors (PEs) as dependent measures.

Given our sample included a notable proportion of ambidextrous participants, we conducted a preliminary analysis with handedness as a factor to assess its potential influence on our variables of interest. This analysis revealed that handedness did not significantly affect either spatial compatibility ($F(2,57) = 0.715$, $p = .493$) or target word type ($F(2,57) = 2.02$, $p = .142$), nor their interaction ($F(2,57) = 0.796$, $p = .456$). Handedness itself did not emerge as a significant main effect ($F(2,57) = 2.34$, $p = .105$). Based on these results, we excluded handedness from subsequent analyses to maintain a more parsimonious statistical model.

6. Results

Data from one participant were excluded from the analyses because the experimental session was interrupted by a mandatory fire drill evacuation of the building, preventing completion of the task. As this participant had already completed a substantial portion of the experiment, rescheduling to complete the remaining trials was not feasible. Therefore, data from 60 participants were included in the final analyses.

Accuracy was measured across the entire task for all participants. There was no evidence of inattention, with the highest error rate (25% for one participant) remaining within acceptable limits for this task type.

Responses to fillers were discarded. Omissions (1.74%) and errors (9.26%) were removed before conducting the analysis on the response times (RT). Given that participants' RTs strongly differed (range: 47 ms–1499 ms), outlying RTs were determined by transforming each participant's RT data points into a z-score (z-score range: $-3.6 + 4.0$). Data points corresponding to z-scores $> +2$ and < -2 were excluded from the analysis (5.12% of trials).

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The results of the ANOVA on the RT latencies revealed a significant main effect of *Target Word*, with slower RT latencies for action relevant (*M*: 721 ms, *SE*: 8.73 ms) than action irrelevant (*M*: 701 ms; *SE*: 8.91 ms) target words ($F(1,59) = 19.82$, Mean Square Error (MSe) = 1156.70, $p < .001$, $n_p^2 = .252$). The main effect of *Spatial Compatibility* was not significant, $F < 1$.

Importantly, the interaction between *Target Word* and *Spatial compatibility* was significant ($F(1,59) = 6.29$, $MSe = 464.71$, $p = .015$, $n_p^2 = .096$), indicating that property verification judgements for action-relevant target words were faster in the spatially compatible condition (*M*: 717 ms, *SE*: 8.74) than in the spatially incompatible condition (*M*: 725 ms, *SE*: 9.17), whereas property verification judgements for action-irrelevant target words were slower in the spatially compatible condition (*M*: 704 ms, *SE*: 9.47) than in the spatially incompatible condition (*M*: 698 ms, *SE*: 8.80). Planned comparisons revealed that for action-relevant words, the difference between spatially compatible and incompatible conditions approached significance, $t(59) = 1.96$, $p = .054$, whereas for action-irrelevant words, the same difference was not significant, $t(59) = -1.50$, $p = .137$. See Figure 2.

Further t-tests aimed at comparing the two kinds of target words (action relevant, action irrelevant) in each compatibility condition (spatially compatible, spatially incompatible) showed that action-relevant words (*M*: 725 ms, *SE*: 9.17) were processed more slowly than action-irrelevant words (*M*: 698 ms, *SE*: 8.80) when the required response was spatially incompatible with the prime object's affordance, $t(59) = 4.85$, $p < .001$. Similarly, action-relevant words (*M*: 717 ms, *SE*: 8.74) were processed more slowly than action-irrelevant words (*M*: 704 ms, *SE*: 9.47) also when the required response was spatially compatible with the prime object's affordance, $t(59) = 2.55$, $p < .013$. Crucially, however, the slowing down of action-relevant words

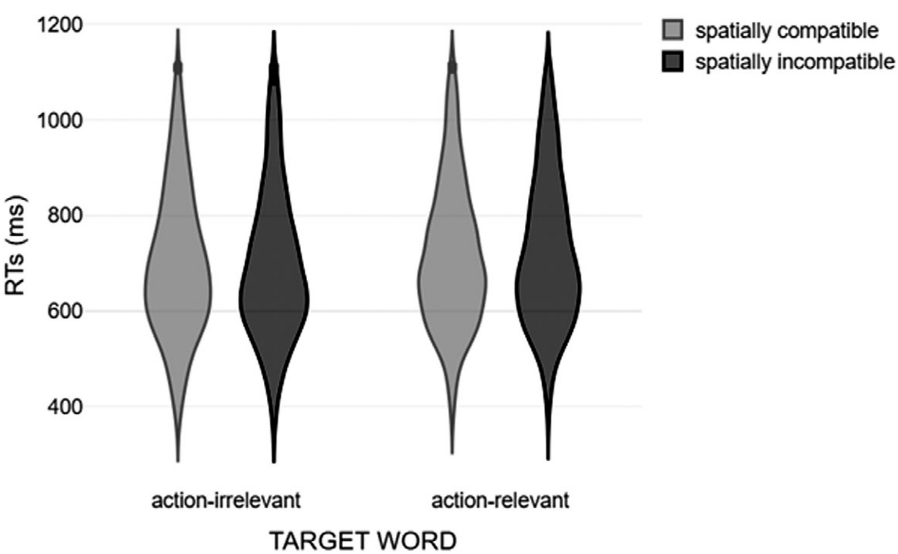

Figure 2. Response time distributions (in ms) across experimental conditions. Violin plots show RTs for action-irrelevant and action-relevant words in spatially compatible (light grey) and spatially incompatible (dark grey) conditions. The width of each violin represents the density distribution of data at each RT level.

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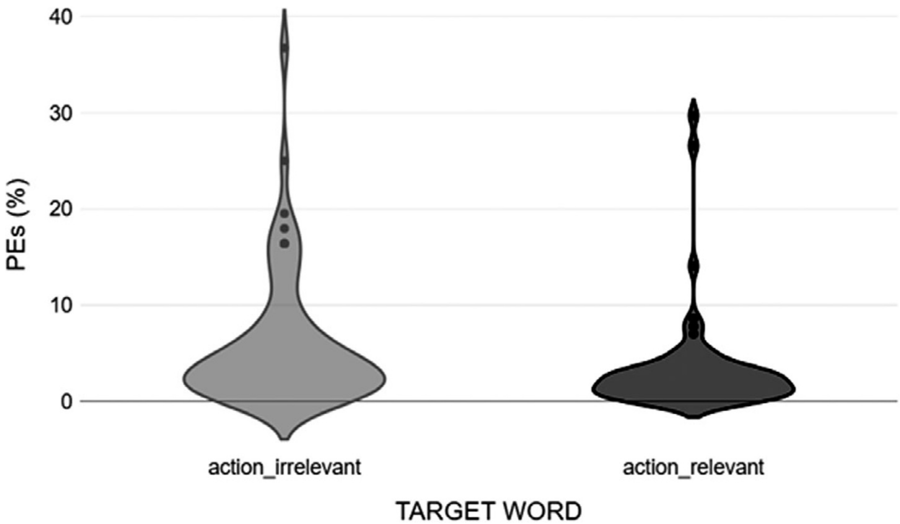

Figure 3. Percentage of errors (PEs) for action-relevant and action-irrelevant target words. Violin plots show the distribution of error rates across participants, with width representing density at each error level.

in the spatially incompatible condition (27 ms) was twice as large as that in the spatially compatible condition (13 ms), $t(59) = 2.50$, $p < .015$.

The ANOVA on the PEs showed a significant main effect of *Target Word* ($F(1, 59) = 7.64$, $MSe = 206.57$, $p = .008$, $n_p^2 = .115$), that is, property verification responses for action-relevant target words (*M*: 6.6%; *SE*:1.35%) were more accurate than for action-irrelevant target words (*M*: 11.8%; *SE*: 1.78%). Results are shown in Figure 3. No other main effect or interaction was significant, $F_s < 0.58$, $p_s > .447$.

7. Discussion

The aim of the present study was to assess whether the availability of contextual action-relevant structural information affects language processing. Specifically, it examined whether observing a prime object (e.g., a frying pan) suffices to pre-activate structural motor knowledge and whether this pre-activated information is then able to selectively facilitate the processing of words describing action-relevant components of the objects.

Our findings support the hypothesis, derived from the *word origin account*, that motor affordances selectively facilitate processing of action-relevant but not action-irrelevant property words. Specifically, we observed an interaction between spatial compatibility and target word, with compatibility effects emerging for action-relevant but not action-irrelevant words. Conversely, our results offer little support for the alternative hypothesis based on the *spatial origin explanation*, which predicted a main effect of compatibility regardless of word type (action relevant, action irrelevant).

Thus, consistent with our predictions, we found an attentionally modulated motor-to-semantic priming effect. In other words, property verification judgements for action-relevant words were faster in the spatially compatible than incompatible condition, whereas judgements for action-irrelevant words did not show any difference between the two conditions. Our findings likely indicate that responding to an

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action-relevant word with a response key spatially positioned consistently with the affordance of a previously encountered object can facilitate performance, presumably because the spatial location of the prime object's affordance was coded in advance. Conversely, responding to an action-irrelevant word with a key positioned consistently with the affordance of a previously encountered object neither facilitates nor hinders performance, as these words refer to motorically irrelevant features of the prime objects.

Taken together, these results argue in favor of a *word origin explanation* of the compatibility effect. Indeed, only the processing of action-relevant words benefited from the activation of structural motor knowledge, leading to faster responses when the response key was located on the same side as the prime object's action-relevant feature. We suggest this result is due to the action-relevant target words emphasizing the position of the corresponding object part in the previously shown prime object. Therefore, structural motor information, activated by observing an object's orientation, may influence language processing to the extent that words being processed are relevant for action with such objects. That is, spatialized object properties are not mandatorily linked to manual response biases; rather, this link is modulated by trial-by-trial changes in conceptual focus as determined by the target word. The finding of a moderation of the object-based compatibility effect by the type of target word (i.e., action relevant, action irrelevant) is not compatible with a *spatial origin explanation* of the effect, because the salience of the visual motor affordances of the prime object, to which supporters of this account would ascribe the compatibility effect, would be predicted to capture people's attention irrespective of the following target word (i.e., action relevant or action irrelevant). Therefore, a main effect of compatibility is predicted by the *spatial origin hypothesis*, regardless of the type of target word presented to participants, which is not what we observed.

Importantly, this result is in line with findings from Lebois et al. (2015), who demonstrated that vertical spatial congruency effects (e.g., faster processing of *sky* when response is "up" vs. "down") also rely heavily on context. That is, the vertical spatial congruency effect only occurred when participants explicitly judged the word's spatial associations. Thus, not even core features of a concept (e.g., *being up* for sky) become activated unless context, in terms of task conditions, makes them salient (for task-dependent influences of motor information on semantic processing see also De Bellis et al., 2016; see García & Ibáñez, 2016 for a review). Also, if the task is performed by relying on a simple word association strategy, i.e., without determining the type of association between the property word and the concept word (for example, whether the property word refers to a part of the concept word as in the concept–property pair "frying pan"-*handle*), then the underlying conceptual representation may not be retrieved at all, thus resulting in motor information being unable to exert a robust influence on language processing (e.g., Scerrati et al., 2021; Solomon & Barsalou, 2004).

Importantly, action-relevant target words led to both slower but also more accurate responses in the ANOVA as in a typical speed-accuracy tradeoff effect. It is worth considering that the time course of distractor processing can produce opposing effects on target processing (e.g., Mittelstädt et al., 2022). Time-varying distractor-based processes have been shown to influence behavior in priming effects (e.g., Ellinghaus & Miller, 2018). In the current experiment, it is likely that depending on the target word type, different types of prime object distractors became activated, and this, in turn, produced opposing effects on task performance.

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Our results also showed that although action-relevant words were processed more slowly than action-irrelevant words in both spatial conditions, the slowing down was twice as large in the spatially incompatible than in the spatially compatible condition (27 ms versus 13 ms). This finding indicates that the slowdown for action-relevant words was partially driven by spatial compatibility. In addition, this result suggests an advantage for action-relevant words when the required response was spatially compatible rather than incompatible with the prime object's affordance.

Overall, our results support the assumption that observing a graspable object can indeed lead to the activation of the motor actions associated with its use (e.g., Iani et al., 2019; Scerrati et al., 2020a; 2020b; Tucker & Ellis, 1998). Our findings also support the hypothesis that conceptual content is stored in close connection to the sensory and motor areas (Warrington & McCarthy, 1983, 1987; Warrington & Shallice, 1984; see also Damasio, 1989; Farah & McClelland, 1991; Humphreys & Forde, 2001; McRae & Cree's, 2002) and that it likely shares a common neural substrate with the sensory and the motor systems (Barsalou, 1999, 2008, 2016). Effects of action on language such as the motor-to-semantic priming effect shown here can be observed in parallel with effects of language on action (for a review, see Meteyard & Vigliocco, 2008). In sum, our study indicates an influence of motor control on cognitive functions and strengthens the hypothesis that the language and sensory motor systems are tightly linked in the human brain (Goldstone & Barsalou, 1998).

Several limitations of the current study should be acknowledged. First, our stimulus set was relatively small, including only four different objects, which may limit the generalizability of our findings. Future research should employ a larger and more diverse set of objects to confirm whether the observed effects extend across different object categories with varying affordance properties. Second, while our reported analyses focused on right-handed participants, our sample actually included a mix of right-handed individuals and ambidextrous participants, with data from only one left-handed participant. This prevents us from systematically examining how handedness might modulate the observed effects. Future studies should include balanced samples of left-handed, right-handed and ambidextrous participants to investigate whether affordance effects on verbal processing vary with manual dominance. Additionally, our study focused solely on the visual presentation of objects and did not explore whether similar effects would occur with actual object interaction or following different types of sensorimotor experience. Future studies could manipulate participants' prior physical interaction with objects to determine whether direct motor experience differentially affects subsequent verbal processing. Finally, neuroimaging methods could provide valuable insights into the neural mechanisms underlying the observed motor-to-semantic priming effects, particularly regarding the specific brain networks involved in processing action-relevant versus action-irrelevant object properties.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/langcog.2025.10017.

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Ethics approval. The experiment was conducted in accordance with the ethical standards laid down in the Declaration of Helsinki and fulfilled the ethical standard procedure recommended by the Italian Association of Psychology (AIP). All procedures were approved by the department of the university where the study was conducted.

Consent. Informed consent was obtained from all individual participants included in the study.

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