Lexicon in action: N400 contextual effect on affordances and telicity

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Abstract

Traditional semantic theories assume that meaning arises from the syntactic combination of amodal symbols processed by a modular subsystem. This idea has two striking implications: first, sensory-motor experience has no relevance in language processing; secondly, since the domain of syntactic rules is the sentence, linguistic interpretation takes place in a two-step fashion such that discourse-level information is considered only after establishing sentence local meaning. This paper calls into question both these assumptions. Contrary to the predictions of two-step models, in the present ERPs study we found evidence of the power of discourse in overwriting local semantic violations (e.g., using a funnel to *hang* the coat) and in making locally acceptable combinations (e.g., using a funnel to *pour* water into a container) globally incongruent. Since context systematically affected the action possibilities of an object, the current results also challenge traditional theories showing that affordances are immediately integrated in the creation of new meanings.

Keywords: Affordances; telicity; Event-related potentials; N400; embodied cognition; discourse.

Introduction

Classical theories of meaning have been characterized for a long time by two widespread assumptions: first, the definition of meanings as amodal mental symbols, and second, the tendency to assume that the sentence is not only the core unit of syntactic analysis, but also the core unit of language interpretation. These ideas are closely related and depend, essentially, on the adoption of the model of the mind-brain relation depicted in the classical metaphor of the computer (Fodor, 1975; Cosentino and Ferretti, in press, for a related discussion). The present paper is concerned with two crucial implications of these claims, namely that sensory-motor experience has no relevance in language processing, and that local semantic constraints have precedence over global contextual factors. Let us introduce them in turn.

A main assumption of classical theories of meaning in cognitive science has been that meaning arises from the syntactic (i.e. rule-based) combination of amodal symbols that are independent of any specific sensory modality and are, as such, unrelated to the perceptual features of the entities in the world which they refer to (e.g., Fodor, 1975; Pylyshyn, 1984). This approach has been recently formalized by a computer-based mathematical high-dimensional model of meaning, Latent Semantic Analysis (LSA) (Landauer and Dumais, 1997), which has been presented as a new variant of the classical symbolic theories. The model attempts to derive and represent meanings from statistical analyses of patterns of language use in large corpora. The underlying idea is that the information about the linguistic contexts in which a word does and does not appear mutually constrains many words and determines the similarity of their meanings. In this view, meanings are represented as vectors in a high-dimensional space and defined in terms of lexical co-occurrence and semantic relatedness. That is: the meaning of a word is derived by its relations to other words and other mental symbols.

This conclusion strikingly contrasts with the emphasis that an alternative account of meaning, the *embodied* account, has recently placed on the role of perceptual and motor states acquired during experience with the world and the body. According to the embodied theories, language comprehension recruits areas of the sensory-motor cortex dedicated to action, perception and emotion (Barsalou, 1999; Werning, 2012). In the present paper, we intend to focus on a notion that is particularly relevant in the theoretical framework of the embodied account, the notion of *affordance*. Following Gibson (1979), affordances are defined as qualities of an object or an environment that, in combination with a particular bodily structure, allow an individual to perform an action.

Evidence exists that perception of object-related actions and objects alone modulates activity in the motor system. In non-human primates, a set of neurons called "canonical neurons" respond when monkeys perceive manipulable objects (Murata et al., 1997), and similar effects have been shown in the human brain as well (see for a review Martin, 2007). Showing that the perception of manipulable objects activates the very system responsible for the actual manipulation, these studies demonstrate that the brain responds to the affordances of an object. The hypothesis that we discuss in this article is that the kind of embodied world-knowledge related to object affordances is also crucially involved in language processing.

While there is substantial evidence for a role of the motor cortex in action-related language understanding, the issue whether or not concrete nouns also elicit a similar response in the motor system (as predicted by the embodiment theory) has been less investigated. A TMS study presenting nouns alone does indicate an involvement of ventral premotor cortex (PMv) in the processing of tool-related words (Cattaneo et al., 2010). In behavioural studies, it has been shown that the presentation of nouns can interact with motor activity. For example, the preparation of actions directed toward everyday objects (e.g., glass) facilitated the semantic activation of nouns (e.g., mouth) related to the action goals of the object (Lindemann et al., 2006).

In the present study we used the electroencephalography and recorded event-related potentials (ERPs) to explore how the brain combines affordances during a story comprehension task. We focused on the N400 component, a negative ERP deflection seen around 400 ms after stimulus onset and localized specifically at centro-parietal regions. The N400 has become particularly relevant in language studies as research has shown that it is closely linked to the processing of meaning (Kutas and Federmeier, 2011). Specifically, it reflects routine sense-making processes by which words are related to their semantic context. This leads us to the second main issue investigated in this study.

Classical theories of meaning are characterized by their adhesion to Frege's compositionality principle, which states that the meaning of an utterance is a function of the meaning of its parts and of the syntactic rules by which these parts are combined. Since the domain of syntactic rules is the sentence, the implication of this idea has been the *local meaning hypothesis*, namely the notion that local semantic representations, at word and sentence level, are established prior to discourse global meaning (Kintsch, 1988; Myers and O'Brien, 1998; Kintsch & van Dijk, 1978). To be sure, supporters of this view do not ignore that global contextual information has to be taken into account to help fixing the final interpretation of an utterance. The discussion is about when exactly this happens. Classical theories of meaning presuppose a two-step model of interpretation (e.g., Grice, 1975; Borg, 2012). First, the literal interpretation of the sentence is computed by combining fixed word meanings in ways specified by the syntax, and second, information from prior discourse, world knowledge and other sources of extra-linguistic information are used to integrate sentence meaning. In this view, the first step of the process is necessary and it determines sentence's truth conditions. The role of contextual information at this stage is limited to cases of indexicality and ambiguity. According to this perspective, then, language processing proceeds in a bottom-up fashion, incorporating contextual information only after establishing phrase or sentence local meaning. A crucial aspect of a two-step perspective on interpretation is that local semantics cannot initially be overruled by the wider context.

By contrast, single-step models assume that every source of information that constrains the interpretation of an utterance can be immediately taken into account. Thus, the wider context of discourse has an immediate effect on the interpretation of the unfolding linguistic information. Accordingly, contextual information may be used in a top-down fashion, such that the local contribution of individual words or sentences is a function of the construction of a situational interpretation at the global meaning level.

In order to test the diverging predictions of two-step and single-step models, we examined the interplay between discourse-level global context and a specific type of locally supplied constraint which, to our knowledge, has never been investigated before, that is *telicity*. The term "telicity" is used here with the technical meaning introduced by Pustejovsky (1995) to refer to a component of a lexical entry that specifies the function or the purpose of an object (it is different, then, from the standard use of this term in linguistics to discuss verb semantics). We tested the viability of the claim that local semantics cannot initially be overruled by the wider context by examining whether or not discourse context can overrule the impact of telicity. As contextual manipulations systematically modified the affordances of the objects, we directly contrasted telicity with context-driven affordances. This was accomplished in two ways: first, we analyzed whether context-driven affordances can overwrite local violations of telicity (i.e., the case in which a word in a telic combination is locally anomalous but globally congruent); second, we investigated whether discourse-level information can be even used to temporarily de-activate the telic component of the meaning of nouns (i.e., the situation in which context-dependent affordances make a locally congruent combination globally incongruent).

Table 1. Example of experimental stimuli

Context	Example sentences	TELIC	NON TELIC
NEUTRAL	Chiara si è attrezzata con un imbuto per fare in casa un piccolo esperimento di chimica e, a tal fine, ha messo un colorante nell'acqua. *Clare got herself a funnel to perform a little chemistry experiment at home and to this end she put a dye in water.*	**NeuT** Una volta fatto ciò, usa l'imbuto per versare l'acqua in un contenitore. *Once she has done so, she uses the funnel to pour the water into a container.*	**NeuNT** Essendo un tipo originale, usa l'imbuto per appendere il cappotto. *Being an unconventional person, she uses the funnel to hang her coat.*
SUPPORTIVE	Chiara ha un imbuto in più e, dopo aver deciso cosa farne, lo inchioda per bene al muro lasciando la parte più stretta rivolta verso l'esterno. *Clare has an extra funnel and, after having decided what to do with it, she glues it to the wall leaving the narrow end facing outward.*	**SuppT** Una volta fatto ciò, usa l'imbuto per versare l'acqua in un contenitore. *Once she has done so, she uses the funnel to pour the water into a container.*	**SuppNT** Essendo un tipo originale, usa l'imbuto per appendere il cappotto. *Being an unconventional person, she uses the funnel to hang her coat.*

Methods

Participants

Twenty-two right-handed native speakers of Italian (13 males; mean age = 29,2 years, range 20 to 50 years) participated in this study. All had normal or corrected-to-normal vision. None of the subjects had any neurological or psychiatric disorder, had experienced any neurological trauma, or used neuroleptics. They were paid for their participation.

Stimuli

We created Telic and Non telic combinations between a noun describing an object and a verb describing an action (for example, "*funnel* and *pour*" vs. "*funnel* and *hang*". We then created 80 short stories in which those combinations were preceded by a Neutral context, and 80 variants in which the same combinations were preceded by a Supportive context, obtaining 4 experimental conditions in a 2x2 design (see Table 1): (1) NeuT "Neutral Telic", (2) NeuNT "Neutral Non telic", (3) SuppT "Supportive Telic", (4) SuppNT "Supportive Non telic". A pre-test was conducted which consisted of the matching of semantic similarity values (SSVs) for the four conditions. We translated the material into English and submitted it to Latent Semantic Analysis (LSA; Landauer and Dumais, 1997) available on Internet at http://lsa.colorado.edu/.

First, we confirmed that Telic combinations (i.e. *funnel-pour*; mean SSV=.30) were indeed more semantically related (and thus more predictable) then Non telic pairs (i.e. *funnel-hang*; mean SSV=.13) ($t(39)=5{,}449$, $p=.000$). Second, we checked that each continuation (Telic or Not telic) was matched in terms of relatedness and associative strength to its context in order to rule out that the N400 could be manipulated by these factors (NeuT vs. SuppT: $t(39)=.496$, $p>.05$; NeuNT vs. SuppNT: $t(39)=.288$, $p>.05$).

Procedure

Each trial started with a fixation cross (1300 ms) followed by the presentation of the context-setting sentences shown all at once. Context duration in ms was computed as (n × 400), n=number of phrases, with a 5 phrases maximum. After a fixation cross of 1300ms, the phrase by phrase presentation of the sentential context started, with a 450 ms phrase duration and a variable random 250-450ms inter-stimuli interval. The test sentence followed word-by-word. Each word was displayed at the center of the PC monitor for 450 ms, with a 250-450 ms pseudo-random blank interval between successive word presentations such that the critical word was always followed by a 450 ms interval.

Two trial lists were used. For the first list, 40 Telic combinations and 40 Non telic combinations were presented in as many Neutral and Supportive contexts (20 NeuT, 20 SuppT, 20 NeuNT, and 20 SuppNT stories), and were randomly mixed with 40 filler stories. The second list was derived from the first by replacing all the Telic combinations by their Non telic counterparts and vice versa. The total of 120 stories was divided into 4 blocks separated by a break, the duration of which was determined by the participant. Total time-on-task was approximately 40 minutes. Subjects completed the task in two separated sessions. In the second session they were assigned to the list that they did not see in the first session, such that at the end of the two sessions each subject had read 160 stories (40 per condition) excluding fillers. In order to avoid the effect of word repetition within the same session, and to minimize other potential memory effects across sessions, we required each participant to undertake the second session only after a minimum interval of two weeks from the first one.

Electroencephalogram recording and data processing

Using a BrainAmp acticap recording system, the electroencephalogram (EEG) was recorded from 66 active electrodes including four electro-oculogram electrodes for monitoring horizontal and vertical eye movements. EEG and EOG signals were digitized at 1000 Hz and with an online band-pass filter of 0,53 – 70Hz. Impedance was kept below 5 kΩ for scalp electrodes and below 10 kΩ for EOG electrodes. The EEG data were processed using Brain Vision Analyzer 2.0 software. All EEG channels were re-referenced off-line to the average of the left and right mastoid electrodes (TP9 and TP10) and filtered with a high cutoff of 30 Hz, 12 dB/oct. An automatic raw data inspection rejected trials with amplitude differences exceeding 200 μV in a 200 ms time interval and with activity lower than 50 μV in a 100 ms interval. Ocular artifacts were corrected by means of a procedure based on independent component analysis (ICA). Single-trial waveforms were separately extracted during 1200 ms epochs (starting 200 ms before critical word onset), averaged, baseline corrected to 200 ms pre-stimulus onset and screened for artifacts. Segments with potentials exceeding ±90 μV were rejected. One participant was excluded due to excessive artifacts (trial loss = 50%). For the remaining 21 participants, average ERPs were computed over artifact-free trials per condition (average percentage of included trials = 96%, range = 72–100% across the four conditions).

Statistical analysis

Using average amplitude per condition across all EEG electrodes, a 2(Context: Neutral, Supportive) × 2(Combination: Telic, Non telic) repeated measures analysis of variance (ANOVA) was performed in consecutive 100 ms time windows between 200 and 600 ms after critical word onset, which corresponds to the time interval during which N400 deflections and experimental effects were found to be most pronounced (Kutas and Federmeier, 2011). Then, additional ANOVAs were performed to explore the scalp distribution of the observed effects adopting a systematic columnar "pattern of analyses" similar to that used in other studies (e.g., Paczynski and Kuperberg, 2012).

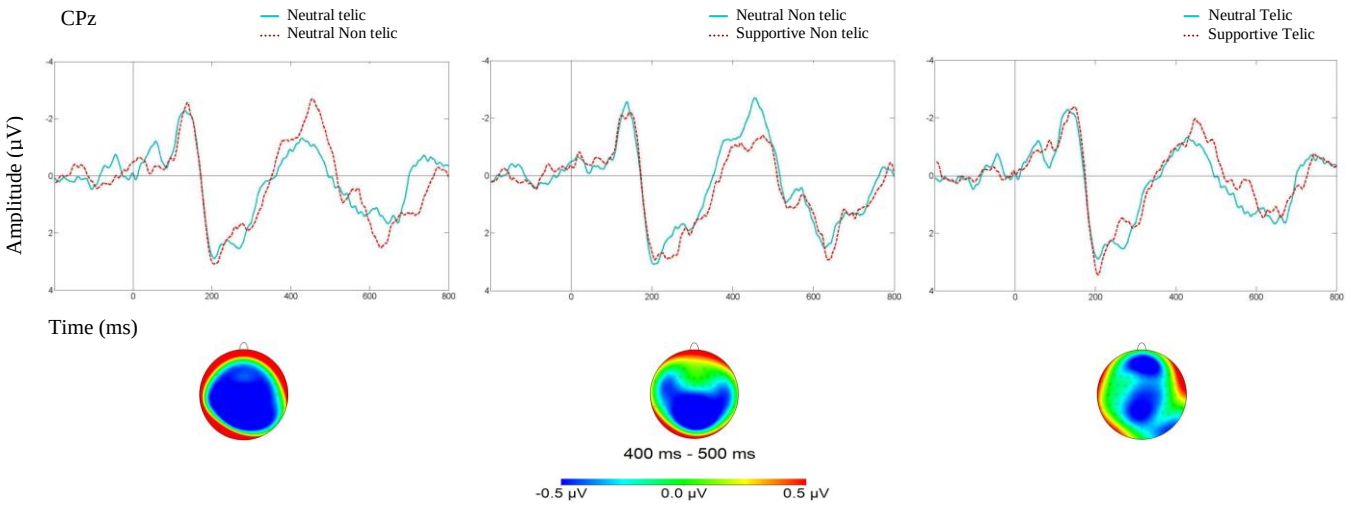

Figure 1. Grand average waveforms and the scalp distribution of the N400 effects. From left to right, the differences are shown between NeuT and NeuNT conditions (Neutral Non telic minus Neutral Telic), NeuNT and SuppNT (Neutral Non telic minus Supportive Non telic), NeuT and SuppT (Supportive Telic minus Neutral Telic).

This approach allows to detect differences in the distribution of effects along the anterior-posterior (AP) axis of the scalp, and at lateral electrode columns it allows the detection of differences across the two hemispheres. ERP amplitudes were measured at midline electrodes and at 8 peripheral columns obtained dividing the electrodes along left–right, medial-lateral, and dorsal–ventral dimensions. ANOVAs were performed with the variables Context (2 levels: Neutral, Supportive), Combination (2 levels: Telic, Non telic), Anterior-Posterior (AP) distribution (number of levels depending on the number of electrodes in each column), and, at peripheral sites, Hemisphere (2 levels: left, right). Follow-up ANOVAs were performed when interactions were found, specifically on a predetermined region over centro-parietal sites (including CP1, CP2, CPz, Pz, P1, P2, POz) where the N400 is maximal (Kutas and Federmeier, 2011). The Greenhouse-Geisser correction was applied to F tests with more than one degree of freedom in the numerator to protect against Type 1 errors resulting from violations of sphericity (corrected p-values and degrees of freedom are reported). Bonferroni-adjusted planned comparisons were performed to decompose the effect of trial type.

Results

The grand average ERP waveforms elicited by Telic and Non telic words in Neutral context, and the difference between the grand average waveforms elicited by Non telic words in Neutral and Supportive contexts and by Telic words in the same two contexts are shown in Figures 1. As expected, replicating the standard N400 effect due to semantic violations, we found that in Neutral context critical words elicited more negative N400 in Non telic condition compared to Telic condition. However, a key finding was that the N400 elicited by Non telic words in Neutral contexts was considerably reduced when these words were preceded by a Supportive context. The other key finding was that the N400 effect could also be elicited by Telic critical words when they were preceded by a Supportive context compared to a Neutral context.

The omnibus ANOVA confirmed that the interaction between Context and Combination was significant in the 400-500 ms time interval, $F(1, 20) = 5.110$, $p=.035$. Following-up on this effect, we systematically explored its topography. We were able to establish that the interaction between Context and Combination was still significant in the Midline analysis, $F(1, 20) = 5.202$, $p=.034$. We also found a significant interaction between Context and AP distribution, $F(1.936, 38.712) = 3.724$, $p=.034$ and a three-way Context × Combination × AP distribution interaction, $F(1.862, 37.249) = 4.305$, $p=.023$. The interactions with AP distribution indicated a larger effect over central-posterior electrodes.

Significant interactions between Context and Combination were found in dorsal-medial, $F(1, 20) = 4.395$, $p=.049$ and dorsal-lateral columns as well, $F(1, 20) = 4.756$, $p=.041$. Along the dorsal-medial sites there was also a significant three-way interaction between Context, Combination and AP distribution, $F(1.466, 29.317) = 8.762$, $p=.003$, whereas at the dorsal-lateral sites the Context × AP distribution interaction was only trend-wise significant, $F(1.726, 34.520) = 2.938$, $p=.073$. No interactions with Hemisphere were found, indicating that the distribution of the effect is central. No other main effects or interactions were found at the ventral-medial sites, where the interaction between Context and Combination only approached significance, $F(1, 20) = 3.866$, $p=.063$, nor at the ventral-lateral sites. Follow-up ANOVA of the predetermined N400 region showed a significant Context × Combination interaction, $F(1, 20) = 11.267$, $p=.003$. There was no interaction with electrodes in this region showing that the effect was distributed across all the sites.

Planned comparisons allowed decomposing the effect of trial type. First, replicating the standard N400 effect to semantic violations, we found that a Non telic combination elicits an N400 effect (M = -1.67 μV) compared to the baseline Telic condition (M = -.64 μV) in Neutral context, $t(20)=3.069$, $p=.006$, CI = [.33, 1.73]. However, the N400 for the same Non telic combination is reliably less negative in Supportive context (M = -.88 μV), $t(20) = -2.745$, $p=.012$, CI = [-1.39, -.19]. Moreover, a significantly more negative N400 was elicited by Telic combinations in Supportive context (M = -1.15 μV) compared to the same combinations in Neutral context, $t(20)=2.276$, $p=.034$, CI = [.04, .98]. By contrast, ERP amplitudes for the Neutral/Telic and Supportive/Non telic conditions did not reliably differ, $t(20)=.951$, $p>.05$, nor did for Neutral/Non telic and Supportive/Telic conditions, $t(20)=-1.572$, $p>.05$.

Discussion

The analysis of the N400 amplitudes led to the key findings that discourse context has effects in (1) deleting local telic violations, and (2) generating global affordance violations. These results are relevant to the current debates on two closely related topics: the nature of meaning (symbolic vs. embodied), the role of context in lexical interpretation and in sentences' truth-conditions. Let us discuss them in turn.

The nature of meaning: Symbolic vs. Embodied accounts

An important focus of our experiment was the process of new meaning creation. According to symbolic accounts of meaning, like high dimensional models (Landauer and Dumais, 1997), two words can be meaningfully related only if they are either semantically and/or associatively related. Semantic similarity or associative strength can be objectively quantified in terms of Semantic Similarity Values (SSVs) using the method of Latent Semantic Analysis (LSA). Grounding on this assumption, symbolic accounts predict that the plausibility of a sentence will be related to some measure of SSVs between words within the sentence or the discourse context. However, as revealed by their low SSVs, words in Non telic pairs were neither semantically nor associatively related, nor could other measures of SSVs differentiate between Telic and Non telic conditions. In spite of that, we found that the N400 for the telicity violation condition ("She uses the funnel to hang her coat") was significantly smaller in the Supportive context than in the Neutral context. This result indicates that the effect of the local violation of telicity was "neutralized" by the context, which made the locally anomalous word globally acceptable. It is important to note that the same Non telic critical words elicited a standard N400 effect compared to Telic words in Neutral contexts, which means that Non telic words were indeed well suited to generate semantic violations as reflected by the N400 effect. Crucially, Supportive contexts were designed to be unusual enough to guarantee that the situation depicted in them was novel to the participants, namely that they would have very unlikely experienced such a situation before (it is quite unlikely that everyone has ever used a funnel to hang the coat). Thus, in order to make sense of those sentences, people had to rely on a different type of knowledge: the knowledge derived from their previous physical interactions with funnels, even if not in the specific situation suggested by the Supportive context. Sentences like the one reported above make sense only if people are able to extract the affordances of the object and recombine them with a certain action to establish if the mentioned object can accomplish the goal described by the sentence.

A possible objection to the involvement of affordances in those scenarios could be that people simply extract relevant information concerning objects from their semantic memory, which includes pre-stored world knowledge like the fact that funnels are shaped in a certain way and are often made of rigid materials. After retrieving enough facts about funnels, people would be finally able to infer that a funnel can be used as a coat rack, as it fulfills all the relevant criteria. If this reasoning were correct though, we should expect longer elaboration times for people to decide whether a funnel can be used to hang the coat compared to establishing whether it can be used to pour water. In contrast, however, we did not find any significant difference in the N400 amplitudes when comparing the Supportive/Non telic condition to the baseline condition (Neutral/Telic). This is crucial as it shows that the new action possibilities for the object, suggested by the Supportive context, were *immediately* extracted and integrated while reading the sentences. Deriving affordances in unusual contexts occurs with the same ease than deriving telic properties for familiar actions.

The role of context in lexical interpretation and sentences' truth conditions

A second relevant finding was that the N400 amplitudes were more negative for Telic combinations ("She uses the funnel to pour water into a container") in Supportive context compared to the same combinations in Neutral context. This shows that the discourse context affected the interpretative process at the local level to the extent that the telic component of the noun was overwritten by the new context-dependent affordances of the object. Given that the N400 appeared immediately on reading the critical telic word, it seems unlikely that the telic component was activated by default and subsequently de-activated. More likely, the new meaning for funnel was selected as the first option on the immediate integration of discourse-level information. These results challenge traditional theories of meaning which assume that linguistic interpretation is construed as a two-step procedure in which a pragmatic-free level of semantic content is computed by default, and only at a later stage this content can be revised to accommodate the pragmatically construed interpretation of the utterance. Evidence that in our experiment there seems to be no default activation of the telic properties of the nouns suggests that the meaning is immediately contextualized. This is consistent with recent work in the field of *lexical pragmatics* (Wilson and Carston,

2007), which emphasizes that the distinction between semantics and pragmatics can be applied also at the level of individual words or phrases rather than whole sentences. In such a view, the meanings of words are often pragmatically adjusted and fine-tuned in context, in accordance with speakers' needs and gleaning opportunistically to what they know about the world, their interlocutors, and previous discourse. Understanding a word in context may involve then the construction of an 'ad hoc' concept or occasion-specific sense, which is based on encoded concepts, contextual information and pragmatic expectations (Wilson and Carston, 2007). Importantly, most current approaches to lexical pragmatics maintain that the occasion-specific senses created by the pragmatic interpretation of individual words and phrases are components of the proposition explicitly expressed by the speaker. According to this *contextualist* thesis, there is no level of semantic content that is independent of pragmatic processes. Hence, the meaning of a word can be interactively established considering at the same time both local constraints deriving from its lexical features and global contextual factors (including constraints resulting from previous discourse and from sensory-motor experience), with no principled precedence of the first on the latter. Whereas two-step models do not allow for the immediate integration of contextual information, single-step models predict that both types of constraint can be simultaneously activated during discourse processing. The latter, then, can account better for our results.

Conclusion

In the present study we have shown that language understanding activates sensory-motor cortex to extract the affordances of objects during the process of creating new meanings in novel contexts. The role of affordances in language understanding cannot be easily conciliated with amodal symbolic accounts of meaning, and is consistent, instead, with embodied theories of language and cognition. As in our study affordances are derived taking into account the information provided by the context, their immediate effect in deleting local telic violations and in making a locally congruent combination globally inacceptable suggests that there is no principled temporal or functional precedence of local constraints over global contextual factors. Taken together, the present results support a notion of language that, unlike the traditional symbolic and modularistic view, is more interactive and grounded on people's bodily experience in their physical environment.

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