Brain Research 1714 (2019) 202–209

Contents lists available at ScienceDirect

Brain Research

journal homepage: www.elsevier.com/locate/brainres

Research report

Concrete processing of action metaphors: Evidence from ERP

Vicky T. Lai[a,*], Olivia Howerton[b], Rutvik H. Desai[b,*]

[a] Department of Psychology and Cognitive Science Program, University of Arizona, 1503 E University Blvd, Tucson, AZ 85721, USA
[b] Department of Psychology, University of South Carolina, 1512 Pendelton Street, Columbia, SC 29208, USA

HIGHLIGHTS

- We investigated sensory-motor activation timing during action metaphor comprehension.
- Concrete verbs elicited bigger N400s than abstract verbs, at frontal sites.
- The metaphoric usages elicited bigger N400s than abstract verbs, at all sites.
- The metaphoric usages elicited bigger N400s than concrete usages, at posterior sites.
- We concluded that the metaphoric sense is grounded in concrete action semantics.

ARTICLE INFO

Keywords:
Metaphor
Concreteness
Semantics
Grounded cognition
Sentence processing
ERP

ABSTRACT

The timing of sensory-motor activation during the comprehension of action verbs used in a metaphorical sense is not well understood. In the present Event Related Potential (ERP) study, participants read verbs in metaphoric (*The church bent the rules*), literal-concrete (*The bodyguard bent the rod*), and literal-abstract (*The church altered the rules*) conditions. The literal concreteness effect, obtained by subtracting the abstract from the concrete, was revealed as an N400, frontally distributed. A metaphoric effect, obtained in the metaphor-abstract contrast, was a widespread N400, and included the frontal response seen in the literal concreteness effect. Another metaphoric effect, obtained in the metaphor-concrete contrast, was a posterior N400. Further time window analyses showed that the literal concreteness effect primarily came from 200 to 300 ms, the metaphoric-concrete effect primarily came from 200 to 400 ms, and the metaphoric-abstract effect was significant throughout 200–500 ms. These results suggest that a concrete but underspecified meaning consistent with metaphoric and literal readings, was activated early and was sustained throughout the 200–500 ms window. We concluded that the metaphoric sense is based in concrete action semantics, even if these senses are underspecified.

1. Introduction

People often use metaphors to reason about abstract concepts. According to cognitive linguistic theories (Lakoff and Johnson, 1999, Gibbs, 1996), metaphor is essentially a set of ontological correspondences (a.k.a. mappings) between an abstract and a concrete conceptual domains. According to processing models these mappings are retrieved or constructed in real time (e.g. Gentner et al., 2001; Coulson and Matlock, 2001). For instance, comprehending the linguistic expression "*She saw what it meant*" requires the retrieval of a conceptual mapping "understanding is seeing" between visual perception and understanding. Likewise, comprehending the expression "*She grasped the idea*" requires the mapping "understanding is grasping", mapped to action related domains. Several neuroimaging studies provided evidence for the involvement of the concrete domain, by demonstrating sensory-motor activations during metaphor comprehension. Reading tactile metaphors (e.g., *a rough day*) or taste metaphors (e.g., *a sweet girl*) activates sensory regions responsive to touch and taste (Lacey et al., 2012; Citron and Goldberg, 2014). Reading metaphors with action content (e.g., *grasp an idea*) activates motor regions involved in motor perception and planning (Desai et al., 2011; Boulenger et al., 2012; Lauro et al., 2013; Desai et al., 2013).

When does the sensory-motor recruitment occur during the comprehension of metaphoric expressions? That is, are the verbs in metaphorical context (*see, grasp*) comprehended in their concrete sense first? The timing issue is important for a number of theoretical considerations. Considering embodied cognition, if the sensory-motor activation is early, then it would support the important role of concrete, bodily experiences in comprehending abstract meaning (Gallese and Lakoff, 2005). If it is activated late, then such activation can be interpreted as

* Corresponding authors.
E-mail addresses: tzuyinlai@email.arizona.edu (V.T. Lai), desairutvik@gmail.com (R.H. Desai).

https://doi.org/10.1016/j.brainres.2019.03.005
Received 14 August 2018; Received in revised form 8 February 2019; Accepted 6 March 2019
Available online 07 March 2019
0006-8993/

being epiphenomenal (Mahon and Caramazza, 2008). Relatedly, early concrete meaning activation would also seem to be in line with a "literal-first" view, where literal-concrete meaning is accessed first and metaphoric meaning is computed only if the retrieved literal-concrete meaning is rejected (Grice, 1975; Searle, 1975). The present study used Event Related Potentials (ERP) to investigate the activation timings of a word's literal-concrete meaning and metaphoric meaning in sentences.

ERP studies examining concreteness have typically found that concrete words (e.g., *banana*) elicited larger N400 and N700 deflections than abstract words (e.g., *truth*) (Barber et al., 2013; Adorni and Proverbio, 2012; West and Holcomb, 2000; Kanske and Kotz, 2007). The concreteness N400 effect is commonly interpreted in relation to the well-known N400, a negative deflection peaking at ~400 ms, indexing semantic aspects of processing (Kutas and Federmeier, 2011). West and Holcomb (2000) suggested that more semantic information is activated via concrete words than via abstract words. However, Barber et al. (2013) held the semantic association strength constant between concrete and abstract words, and still found the concreteness N400 effect. Additionally, different from the classic N400 effect that distributes over the posterior sites on the scalp, the concreteness N400 effect has a frontal distribution. Thus Barber et al. (2013) argued that the concrete-abstract difference lies not in the amount of semantic information activated, but the underlying knowledge recruited. They proposed that the processing of concrete words additionally activates multimodal features from a distributed cortical network and in depth, whereas the processing of abstract words leads to differential and shallower activations. As for the N700 effect, neither the time frame nor the interpretation are well understood. Many believed that it is related to imagery processing, and Barber and colleagues associated it with the integration of the activated multimodal features for building a coherent mental representation.

Instead of nouns, Dalla Volta et al., (2014) examined the concreteness effect using verbs. They used hand-, foot-, mouth- related verbs (e.g., *to knit*, *to kick*, *to bite*) in contrast with abstract controls (e.g., *to infer*). Different from traditional ERP analysis, they employed an analysis of topographical distribution differences (Topographical ANOVA, Murray et al., 2008) to pinpoint the time when the waveforms of the conditions diverged. This resulted in two time intervals: 200–300 ms and 300–400 ms. In the 200–300 ms interval, concrete verbs showed larger mean amplitudes than abstract verbs in a frontal, motor region in the right hemisphere (RH). In the 300–400 ms interval, such concreteness effect was found in a parietal region, in the left hemisphere (LH). These findings indicated that the concreteness N400 reported in the traditional ERP component analysis may consist of two underlying effects: A frontal one that is related to sensory-motor recruitment, and a parietal one that is linguistically sensitive. This is partially consistent with Holcomb and colleague's older hypothesis using the N400 component type of analysis, where they posited that there is a family of N400s, including an imagery-sensitive N400 and a linguistically sensitive N400 (Holcomb, Kounios, Anderson, & West, but see West and Holcomb, 2000).

A few studies have also examined concreteness at the sense level. Huang et al. (2010) used ERP and visual half-field (VF) paradigm to investigate hemispheric differences in the processing of concrete and abstract senses of the same polysemous noun, selected by an adjective preceding the noun (e.g., *green book* vs. *engaging book*). The concrete sense, compared with its abstract sense, elicited an enhanced and widespread P200 effect (180–240 ms) and a reduced N400 at central-parietal sites in the LH. In the RH, the concrete sense elicited a frontal late negativity from 500 to 1000 ms compared to the abstract sense. The authors argued that the concrete adjectives provided a more predictive/constraining context than did the abstract adjectives for selecting among the senses of the following noun, as reflected by the enhanced P200. And because the concrete context was more predictive, the noun N400 for the concrete sense was less negative than the same noun in its abstract sense. As for the late negativity effect in the RH, the authors associated it with imagery processing, demonstrating the crucial role of the RH in imagery during language processing. These results, at a minimal, indicated differential neural substrates for the processing of concrete and abstract senses, which is partially consistent with Barber et al. (2013).

The majority of ERP studies on metaphor contrasted metaphoric and literal senses at the sense level (e.g., *Their theory collapsed.* vs. *The house collapsed.*) (Coulson and Van Petten, 2002; Lai et al., 2009; De Grauwe et al., 2010; Weiland et al., 2014; Schmidt-Snoek et al., 2015; Forgács et al., 2015). A consistent finding across all studies irrespective of the metaphor types examined is a larger N400 effect for metaphoric relative to literal senses, centrally and posteriorly distributed. The specific timings varied slightly across studies and the interpretations differed. In Lai et al. (2009), conventional metaphoric expressions elicited an N400 effect from 320 to 440 ms relative to literals. They attributed the effect to both the activation of a source domain and the process of mapping between the source and the target domains (cf. Lai and Curran, 2013). An inspection of their stimuli revealed that their literal control primarily consists of only literal-concrete senses, not literal-abstract senses. De Grauwe et al. (2010) examined familiar, nominal metaphors in the form of A-is-B, and reported an N400 effect from 325 to 400 ms. They suggested that it reflected a temporarily accessed literal meaning, deemed anomalous momentarily in a metaphoric context. It is unclear whether such temporarily accessed literal meaning is concrete or abstract, or literal at all for that matter. Weiland et al. (2014) used in a masked priming paradigm and demonstrate that the initially activated meaning is literal. They examined metaphors and metonymies (e.g. The word *Böll* in the sentence *The boy read Böll* is a producer-for-product metonymy). An N400 effect from 250 to 500 ms was found for metaphors and an N400 effect from 200 to 350 ms was found for metonymies. When related literal meaning was primed, the metaphor N400 was reduced, and the metonymy N400, vanished. Our interpretation of their results is that a certain meaning was accessed, but this meaning could be literal or something that is congruent with both literal and metaphoric meaning.

Bardolph and Coulson (2014) addressed the metaphoric embodiment issue directly. They pre-activated participants' motor systems by having the participants move marbles upward and downward, and examined whether such taxation on the motor system would influence the processing of words with high and low spatial attributes, both literally (e.g., *ascend, descend*) and metaphorically (e.g., *inspire*, *defeat*). They found that, for literal words, incongruency between an arm movement and a spatial attribute elicited a larger negativity effect than the congruent ones in the 200–300 ms time window. For metaphoric words, the incongruency effect did not occur until after ~500 ms. They suggested that an ERP correlate of literal embodiment in the 200–300 ms time frame and an ERP correlate of metaphoric embodiment after 500 ms post word onset. Forgács et al. (2015) examined the concreteness effect in metaphors, by examining the comprehension of novel metaphoric (e.g., *thin schedule*), literal-concrete (*printed schedule*), and literal-abstract (*conditional schedule*) expressions. Overall, the novel metaphoric condition patterned with the literal-concrete, and both were more negative than the literal-abstract. In their *ad hoc* analysis using very concrete and very abstract bins, though, the concreteness of the whole expressions mattered. Paradoxically, the very concrete bin patterned with the literal-abstract, and the very abstract patterned with the literal-concrete.

The present study exploits the concreteness effect discussed above to investigate whether there is a concreteness effect for action verbs in a metaphoric context, e.g., "*The church <u>bent</u> the rules*". The action verb (*bend*) is non-literal due to the preceding context where the subject (*the church*) renders literal action implausible. Each verb is contrasted with the same verb used in its literal-concrete sense (*The man <u>bent</u> the rod*) and a literal-abstract verb (*The church <u>altered</u> the rules*). If metaphors are understood mostly in terms of concrete semantics, then the metaphoric vs. literal-abstract contrast should be similar to the literal-concrete vs.

literal-abstract contrast, i.e., the concreteness effect, in terms of its frontal topography and early timing. If metaphors are understood partially in terms of concrete semantics and partially via additional cognitive processes, then the metaphoric vs. literal-abstract contrast should have differential timings as well as different topographies as compared to the literal concreteness effect, with metaphors showing a concreteness response intermediate to concrete and abstract conditions. If metaphors are not understood in terms of concrete semantics, the metaphoric vs. literal-abstract contrast should bear no similarity to the literal concreteness effect, with metaphors showing a response resembling the abstract condition.

2. Results

The accuracy of the comprehension question was 87.4% (SD = 6.7%), indicating that the participants were engaged in reading. The averaged numbers of trials included in each condition each participant were 75 (SD = 7.1) for the LA, 75 (SD = 6.5) for the LC, 74 (SD = 6.9) for the MET conditions, out of 88 trials each condition. There was no statistically significant difference in the numbers of trials between conditions.

The grand averaged ERPs waveforms time-locked to the target verbs in the MET, LA, and LC conditions at a frontal group (4, 5, 6, 11, 12, 13, 19, 20, 112, 118) and a posterior group (60, 61, 62, 66, 67, 71, 72, 76, 77, 78, 84, 85) are plotted in Fig. 1. The topographies of each ERP effect, obtained by subtracting LA from LC (LC-LA), LC from MET (MET-LC), and LA from MET (MET-LA) from 200 to 500 ms are displayed in Fig. 1. Visual inspection indicated that LC elicited larger N400 than LA, most prominent from 200 to 300 ms and also continued on until ~450 ms, frontally distributed. MET elicited larger N400 than LC, starting a little before 200 ms and ending at ~600 ms, with a posterior distribution. MET elicited a larger N400 than LA, focal in the frontal sites and lengthy in the posterior sites. Fig. 2 plots effects every 100 ms from 200 to 500 ms.

N400: Mean amplitudes for all conditions from 200 to 500 ms at the frontal and posterior locations were extracted and entered in a Repeated-Measures ANOVA of 3 conditions (LA, LC, MET) × 2 locations (frontal, posterior). There was no condition × location interaction, $F(2, 54) = 1.82$, $p = 0.17$. On the basis of *a priori* prediction that concreteness effect (LC vs. LA) has a frontal topography (see Introduction), we conducted planned comparisons focusing on the frontal and posterior locations. There were condition effects at the frontal site ($F(2, 54) = 3.836$, $p < 0.05$, partial $\eta^2 = 0.12$) and the posterior site ($F(2, 54) = 7.677$, $p < 0.005$, partial $\eta^2 = 0.22$). The concreteness effect, as reflected by the more negative N400 for LC than for LA, was significant at the frontal location, $F(1, 27) = 5.305$, $p < 0.05$, partial $\eta^2 = 0.16$, but not at the posterior location, $F(1, 27) = 1.651$, $p = 0.21$. The first metaphoric effect, as reflected by the more negative N400 for MET than for LC, was also significant at the posterior location, $F(1, 27) = 8.083$, $p < 0.01$, partial $\eta^2 = 0.23$, but not at the frontal location, $F < 1$. The second metaphoric effect, as reflected by the more negative N400 for MET than for LA, was significant both at the frontal location, $F(1, 27) = 6.308$, $p < 0.05$, partial $\eta^2 = 0.19$, and at the posterior location, $F(1, 27) = 13.549$, $p < 0.001$, partial $\eta^2 = 0.33$.

Time window analysis: Mean amplitudes for all three conditions from three time frames (200–300 ms, 300–400 ms, 400–500 ms) at two locations (Frontal, Posterior) were extracted and entered in a Repeated-Measures ANOVA of 3 conditions × 3 times × 2 locations. The results are summarized in Table 2. There were a time × condition × location interaction, $F(8, 216) = 2.584$, $p < 0.05$, partial $\eta^2 = 0.09$ and a time × condition interaction, $F(4,108) = 2.846$, $p < 0.05$, partial $\eta^2 = 0.10$. This indicates that the result patterns in the 3 time windows differ from one another. Thus, we conducted Repeated-Measures of 3 condition × 2 location in each of the time windows along with condition main effect and planned pair comparisons.

The concreteness effect, as reflected by the more negative N400 for LC than for LA, was significant from 200 to 300 ms ($p < 0.001$, partial $\eta^2 = 0.32$) and marginal from 300 to 400 ms ($p = 0.07$, partial $\eta^2 = 0.12$), at the frontal location. The first metaphoric effect, as reflected by the more negative N400 for MET than for LC, was significant from 200 to 300 ms ($p < 0.05$, partial $\eta^2 = 0.18$) and from 300–400 ms

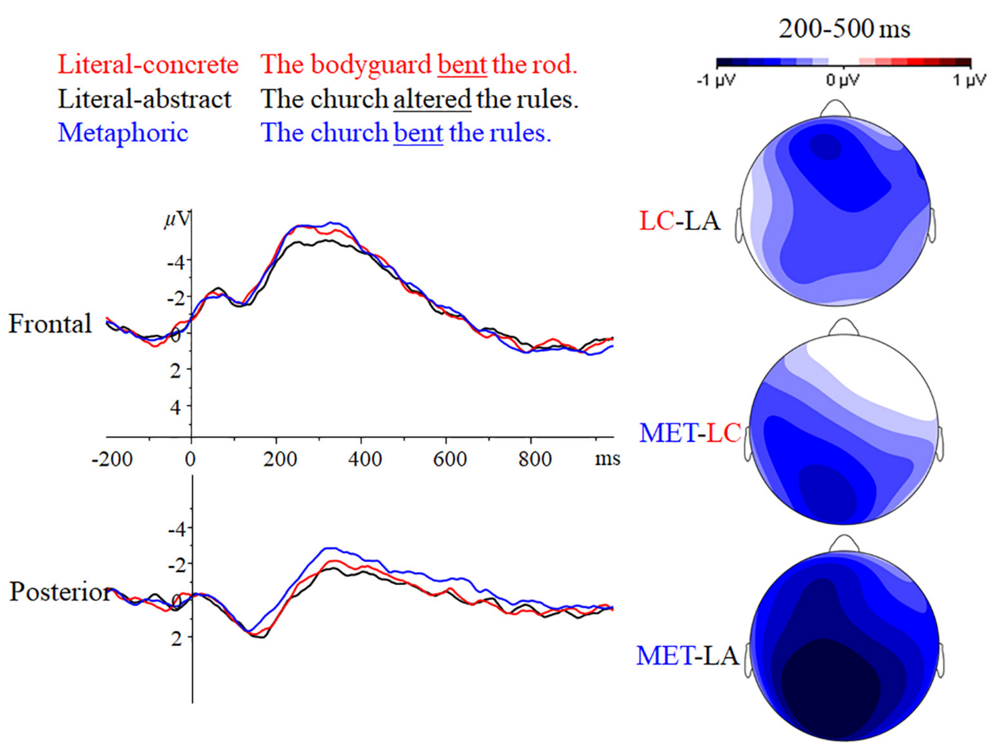

Fig. 1. Left panel: Grand averaged ERPs in the metaphor (MET), literal-abstract (LA), and literal-concrete (LC) conditions at the frontal and posterior locations. Right panel: Scalp distributions of the N400 effects from 200 to 500 ms based on the difference waves between LC and LA, MET and LC, and MET and LA.

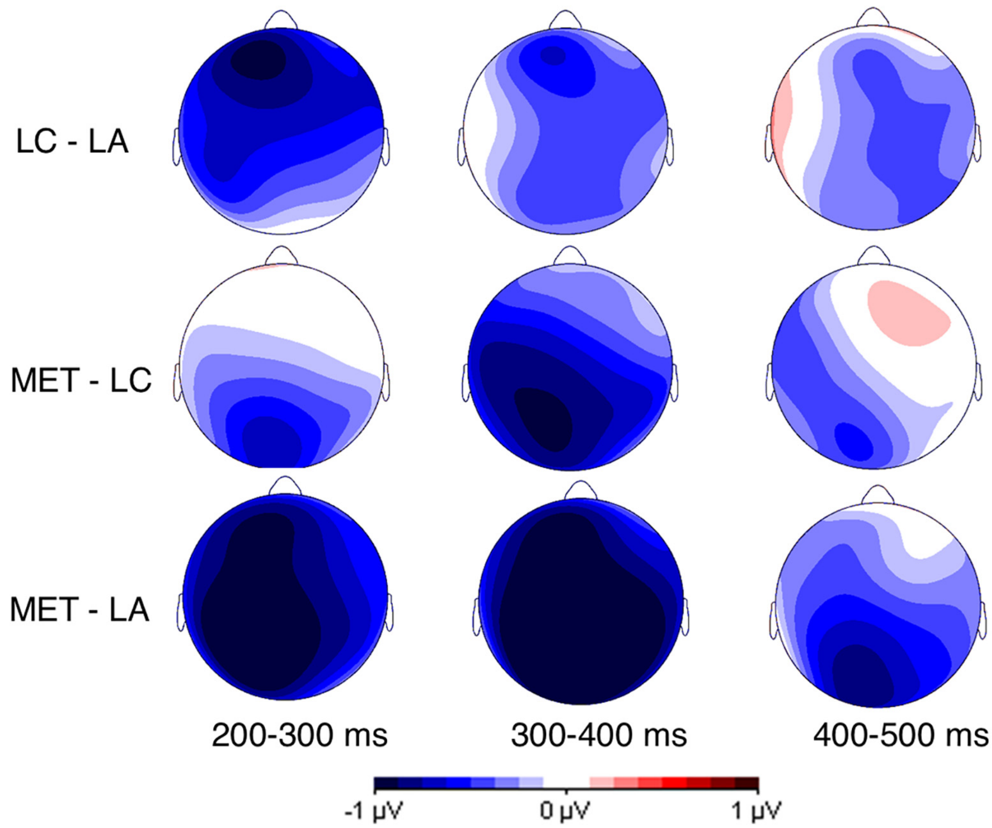

Fig. 2. Scalp distributions of the ERP effects from 200 to 300 ms, 300–400 ms, 400–500 ms based on the difference waves between LC and LA, MET and LC, and MET and LA.

($p < 0.005$, partial $\eta^2 = 0.27$), and was marginal from 400 to 500 ms ($p = 0.09$, partial $\eta^2 = 0.11$), at the posterior location. The second metaphoric effect, as reflected by the more negative N400 for MET than for LA, was significant throughout 200–500 ms and at both frontal and posterior locations (Table 2).

3. Discussion

The present study investigated the timing when sensory-motor recruitment occurs during the comprehension of words used metaphorically. Because ERP correlates of sensory-motor recruitment are not clearly established, we approximated it with the concreteness N400 effect by contrasting concrete vs. abstract word senses in our stimuli (*The man bent the rod.* vs. *The church altered the rules.*). We then compared such literal concreteness effect with the metaphoric N400 effect, contrasting metaphoric vs. abstract word senses in sentences (*The church bent the rules.* vs. *The church altered the rules.*), and with a second metaphoric N400 effect, contrasting metaphoric vs. concrete word senses (*The church bent the rules.* vs. *The man bent the rod.*). All three contrasts were significant. They differed, however, in terms of their topographical distributions. The concreteness N400 effect is distributed frontally, the metaphoric N400 effect relative to literal-concrete is distributed posteriorly, and the metaphoric N400 effect relative to literal-abstract is distributed both frontally and posteriorly. Based on the analysis using three consecutive 100 ms time windows, the significant concreteness effect at the frontal site primarily comes from 200 to 300 ms. The significant metaphoric vs. literal-concrete effect at the posterior site primarily comes from 200 to 400 ms. The significant metaphoric vs. literal-abstract effect is widespread and lasts from 200 to 500 ms.

Our concreteness N400 effect is consistent with past studies (e.g., Barber et al., 2013). In terms of timing, the starting point of our effect is 200 ms, which is earlier than the 250 ms reported in Barber et al. (2013), 350 ms in Adorni and Proverbio (2012), 300 ms in West and Holcomb (2000), and 390 ms in Kanske and Kotz (2007). Such variation may be due to experiment-specific stimuli. It is also likely because we placed the target words in sentences whereas past studies focused on single words. Sentential context - even though it was only a couple of words prior to the target verbs in the current study, may have pre-activated the target verb meaning to some extent and as a result pulled the starting point of meaning processing earlier. This would be consistent with past studies showing word meaning activation by ∼200 ms (Hauk et al., 2006; Kim and Lai, 2012). In contrast, Holcomb et al. (1999) found no discernable difference between concrete and abstract words, when the words were embedded in supportive contexts. One possibility is that their context is longer and perhaps more predictive than ours, pre-activating both concrete and abstract meanings to the same amount, hence the null effect after subtracting one from the other. Another possibility is that their stimuli are nouns and ours are verbs. Typical verbs entail more action content than nouns, leading to stronger motor simulation hence the enhanced concreteness effect. This can be tested in a future study using event nouns with similar action association (e.g., tennis) as verbs.

In terms of topography, our concreteness N400 effect has a frontal distribution, which we interpreted as reflecting the enhanced activation of multimodal features for concrete relative to abstract meanings. Several investigators have suggested that such frontal distribution is due to imagery processing. But Barber et al. (2013) controlled for imageability and associated the effect frontal distribution with recruitment of multimodal features. Dalla Volta et al. (2014) conducted source estimation for their concrete vs. abstract effect in the 200–300 ms window and found a cortical cluster localized in a sensory-motor region around the rolandic fissure. They further took body effectors into consideration and found the sources of the hand-related verb activation in the precentral gyrus and the foot related words in the superior frontal gyrus and medial frontal gyrus. Dalla Volta et al. (2014) did not use ERP analysis whereas we did. Still, the fact that both studies used verbs and found effects in the common time frame 200–300 ms support the interpretation that the present concreteness effect is sensory-motor related.

A number of studies have also associated ERP negativity effect from 200 to 300 ms at the frontal location with embodiment. Boulenger et al. (2006) showed that concurrent motor tasks such as a reaching movement can interfere with the processing of action verbs, within 200 msec post verb onset. Likewise, Bardolph and Coulson (2014) found a frontal negativity from 200 to 300 ms for words (*ascend*, *descend*) whose spatial features were incongruent with participants' arm movement (up or down). The current finding is largely consistent with these studies. But different from these studies, the current study examined action verbs embedded in congruent sentences and they examined how overt motor behavior that primed or occupied sensory motor resources could impact the processing of action words incongruent with the direction of action. Thus our finding is novel in that it provides evidence for the early embodiment of literal concrete language in a more naturally occurring reading scenario.

The central question of the present study was whether there is such concreteness effect during the comprehension of verbs in metaphoric contexts. The short answer is yes. The long and widespread metaphoric effect based on the metaphoric vs. abstract contrast appears to consist of at least two underlying processes: One comparable to the concreteness effect from 200 to 300 ms at the frontal location discussed above, and the other comparable to the effect based on the metaphoric vs. literal-concrete contrast from 200 to 400 ms (see discussion below). Assuming the frontal concreteness effect is related to embodiment, the very same sensory-motor recruitment in concrete literal language takes place for comprehending metaphoric expressions. Thus we propose that metaphoric meaning is not a meaning that gets activated later on during processing. Rather, it starts out as part of a non-specific sensorimotor simulation of the action content, and then gets specified as the context unfolds. In other words, the initial simulation of the action content is compatible with both literal and metaphoric meanings.

Our proposal is consistent with a broader language issue regarding words with multiple meanings (Frisson and Pickering, 2001, Frazier and Rayner, 1990; Frisson and Pickering, 1999; McElree et al., 2006). For instance, Frazier and Rayner (1990) examined homonymous words such as *date* that has a concrete meaning "a bitter-tasting date", which is unrelated to its other, abstract meaning "a romantic date". Likewise, they also tested polysemous words such as *novel* that has a concrete sense "a coffee-soaked novel", which is related to its abstract sense "an interesting novel". They found that, when there was no prior disambiguating context, the dominant/frequent usage was accessed faster than the subordinate usage in homonymous words. But in the case of polysemous words, there was no measurable difference between its concrete and abstract senses. An underspecified meaning that was compatible with both concrete and abstract senses was activated initially, and was then homed in via context (cf. Frisson and Pickering, 2001). In line with this reasoning, here we argue that a meaning representation that was compatible with both the concrete, metaphoric, and abstract senses was activated initially. This meaning representation was then specified early at 200 ms (see also Beretta et al., 2005; Pylkkänen et al., 2006).

The "literal-first" view suggests that literal-concrete meaning is accessed first and metaphoric meaning is computed only if the retrieved literal-concrete meaning is rejected (Grice, 1975; Searle, 1975). The current results do not support this proposal, given that the frontal response to metaphors was similar to the literal-concrete verbs throughout the analysis window, till 500 ms and beyond. If the literal meaning is activated initially and then rejected, one would expect metaphoric and concrete responses to diverge by 200 to 300 ms. This would be consistent with past studies showing word meaning activation by ~200 ms (Hauk et al., 2006; Kim and Lai, 2012). Given the similarity of concrete and metaphoric response frontally, it appears that the metaphoric meaning is based on the concrete sense, or that both meanings are underspecified but contain a sensory-motor element. This is consistent with the majority of the findings showing that metaphoric meaning is as readily available as literal meaning in context (Gerring and Healy, 1983; Keysar, 1989; Blasko and Connine, 1993).

The analysis comparing the metaphoric and concrete conditions (i.e., MET – LC) removes the verb concreteness effect. Such metaphoric effect is mostly consistent with the N400 effects reported in past ERP studies (e.g., Lai et al., 2009; Schmidt-Snoek et al., 2015): Metaphors elicited a N400 effect relative to literal controls that are concrete, and also relative to the abstract controls. The effect started at around 200 ms at posterior electrode sites and became prominent in the 300–400 ms time frame at the central and posterior sites. According to the underspecification account, this is the stage where context homes in the contextually specified, metaphoric meaning. This "homing in" process can be similar to the conceptual mapping process described in past studies (Coulson and Van Petten, 2002; Lai and Curran, 2013), where features from the concrete and abstract concepts are aligned, compared, and imported from the concrete to the abstract concepts (cf. Bowdle and Gentner, 2005).

Forgács et al. (2015) proposed that concrete meaning is first abstracted away to some degree before it gets used for reasoning about the abstract concept. For example, the concrete sense of the word '*fluffy*' in '*fluffy speech*' is activated and is turned into something more abstract before it becomes metaphoric given the context of *speech*. However, this framework deals with novel metaphors, while the current study examined familiar metaphors. Hence, our results do not directly support or contradict this view.

Finally, we note that these data do not directly show involvement of sensory-motor areas of the brain for processing literal or metaphoric action sentences. Here, we only suggest that metaphoric verbs are processed similarly to literal verbs in relation to their concreteness, whatever the sources and causes of the concreteness effects might be. A prior fMRI study using the same stimuli (Desai et al., 2011), did show activation of primary and higher-order motor cortex for processing these literal and metaphoric action sentences, which can be viewed as indirect evidence of the sources of these effects.

In conclusion, metaphorically used action verbs evoked a response that was similar to that of concrete verbs frontally, indicating a concreteness effect starting as early as 200 ms. This suggests that the metaphoric sense is based in concrete action semantics, even if these senses are underspecified. Metaphors also evoke a posterior response that differs from both literal concrete and abstract conditions, possibly reflecting additional cross-domain mapping processes involved in metaphor comprehension. One limitation of the study is the limited amount of context available before the target verb is encountered. Future studies that use more extensive context to enhance metaphoric and concrete senses (e.g., a full sentence or multiple sentences) can potentially provide valuable insights in the effects of context and activation of senses.

4. Methods and materials

4.1. Participants

34 undergraduate students participated in the study for course credits. All were native English speakers, right-handed (Oldfield, 1971), with normal or corrected-to-normal vision. None had any language disorder, neurological disorder, or any major head injury by self-report. Six participants were removed: Two had low numbers of trials (< 50%) after artefact rejection, and four due to EEG system errors. The remaining 28 participants (14 female) included in the analysis were 19.5 years old (range 18–24) on average.

Table 1
Two example sets of stimuli. The target verbs are underlined.

Conditions	Sentences
1. Literal-Concrete (LC)	*The bodyguard bent the rod.*
1. Literal-Abstract (LA)	*The church altered the rules.*
1. Metaphor (MET)	*The church bent the rules.*
Conditions	Sentences
2. Literal-Concrete (LC)	*The cruel pirates captured the marine's vessel.*
2. Literal-Abstract (LA)	*The healthcare issues required the nation's attention.*
2. Metaphor (MET)	*The healthcare issues captured the nation's attention.*

Table 2
Statistical results based the mean amplitudes for Literal-Abstract (LA), Literal-Concrete (LC), and Metaphor (MET), exported from 200–300 ms, 300–400 ms, 400–500 ms at the frontal and the posterior locations. The effect sizes are reported in partial η^2. The notation "n.s." means non-significance. The cells that are gray-out are those that were n.s. or not conducted due to the lack of main effect within the (Frontal or Posterior) region.

Mean amplitudes		200-300 ms		300-400 ms		400-500 ms	
		F	p	F	p	F	p
Frontal	Main effect	6.704	.003	4.909	.012	<1	n.s.
		partial η^2=.20		partial η^2=.15			
	LA vs. LC	12.604	.001	3.550	.07	-	-
		partial η^2=.32		partial η^2=.12			
	MET vs. LC	<1	n.s.	1.887	n.s.	-	-
	MET vs. LA	11.695	.002	8.474	.007	-	-
		partial η^2=.30		partial η^2=.24			
		F	p	F	p	F	p
Posterior	Main effect	6.545	.003	8.417	.001	4.260	.021
		partial η^2=.20		partial η^2=.24		partial η^2=.14	
	LA vs. LC	1.128	n.s.	1.622	n.s.	1.431	n.s.
	MET vs. LC	5.906	.022	10.205	.004	3.161	.09
		partial η^2=.18		partial η^2=.27		partial η^2=.11	
	MET vs. LA	12.846	.001	13.506	.001	8.643	.007
		partial η^2=.32		partial η^2=.33		partial η^2=.24	

4.2. Materials

The stimuli consisted of 88 sets of sentences (Table 1), selected from an fMRI study (Desai et al., 2011) and adapted for an ERP design. All sentences started with a subject noun phrase followed by a target verb, and then an object noun phrase (NP-Verb-NP). In the metaphor (MET) condition, the subject was an inanimate agent (e.g. *the church, the healthcare issues*), followed by an action verb (e.g., *bent, captured*) that could not plausibly be physically performed by the agent. In the literal-abstract (LA) condition, the same inanimate agent (*the church*) was used, but the action verb was replaced by an abstract verb with similar meaning (*altered*). In the literal-concrete (LC) condition, the subject was an animate agent (*the bodyguard*) that could physically manipulate an object (*rod*) whilst the action verb remained the same as the verb in the MET condition (*bent*). Thus, the initial noun phrase served as the context of the verb. In the literal-concrete condition, the animate agent made a physical action possible, while in the metaphoric case the inanimate agent made a physical action impossible or very unlikely, rendering the literal meaning of the verb incongruent. The abstract verbs and action verbs were matched in terms of word length and log transformed word frequency (Brysbaert and New, 2009). There was no statistical difference between conditions (word length 5.5 (SD = 1.5) vs. 5.2 (SD = 1.31); word frequency 2.98 (SD = 0.97) vs. 2.85 (SD = 0.18)).

We matched the familiarity ratings between conditions as familiarity is known to influence metaphor ERP effects (Lai et al., 2009). Ratings were collected via Amazon Mechanical Turk. 30 workers whose native language is English by self-report and whose IP addresses were located within the United States filled out an online questionnaire. The materials consisted of sentences from the LC, LA, and MET conditions, divided into 3 lists using Latin square rotation, such that each condition from each group appeared once in each list. Forty unfamiliar but plausible sentences were included in each of the list (e.g., *A flailing monkey would scare any linguist away)* for quality check purposes, as stimuli that were expected to receive low familiarity ratings. Within a list, the sentences were randomized for each participant. The instructions were: "Some sentences are familiar and can appear in daily newspapers and magazines, whereas others are unfamiliar. Please rate how familiar the sentence is on a 0–6 scale, where 0 is unfamiliar and 6 is very familiar". The averaged familiarity ratings were 4.87 (SD = 1.32) for LA sentences, 4.88 (SD = 1.37) for LC sentences, and 4.71 (SD = 1.31) for MET sentences. The numerical differences were not statistically significant overall (p = 0.34) or between the conditions (LA vs. LC p = 0.92; LC vs. MET p = 0.18; MET vs. LA p = 0.25).

Cloze probability, the probability that the target word is the most likely continuation given its preceding sentential context, was matched between conditions, as it is also known to modulate ERP effects in language studies (Kutas and Federmeier, 2011). Cloze probability values were approximated with the conditional probability of a target word (e.g., "*crushed*" in "*The opposition crushed the argument*") given the word preceding the target word (*opposition*) using the Microsoft Web N-gram services (https://www.projectoxford.ai/weblm). We used various inflected forms of the verb such as –es and –ing, and extracted the conditional probabilities of the target word in each of those forms. The averaged conditional probabilities between conditions were not statistically different (LA vs. LC p = 0.26; LC vs. MET p = 0.89; LA vs. MET p = 0.20).

Yes-no comprehension questions were created for every sentence on every list. For instance, for the sentence "*The mean bodyguard bent the rod*", the comprehension question was "*Was the bodyguard nice?*"

4.3. Procedure

Participants first completed the consent form, in accordance with the University of South Carolina Institutional Review Board. The EEG setup was 30-min, which consisted of placing the sensor net on the head, positioning sensors, and adjusting/rewetting sensors to reach desired impedance levels (< 40 kΩ). After the setup, participants were seated in a quiet and dimly lit room facing a computer screen, 70–80 cm away from the screen, with a button box resting on their lap.

Each trial consisted of a sentence, which was presented word-by-word. The words were in the Courier New font, font size 18, white against black background. Each word was presented for a length-dependent duration (mean = 851, SD = 54, Range 711–1001 ms), followed by a blank/black screen of 500 ms. The last word of the sentence was presented with a period. The participants were instructed to read each sentence silently and attentively. A yes-no comprehension question appeared after 25% of the sentence trials, randomly selected for each participant. The participants were asked to respond "yes" or "no" as accurately and quickly as possible, using the leftmost and the rightmost keys on the button box, using either the left or right thumb. The order of the yes/no keys and the participant number were counterbalanced. Between trials, a screen that said "blink, or continue?" appeared. Participants could choose to blink and rest their eyes before continuing to the next trial by pressing a button at their own pace.

There were 8 practice trials for task familiarization. There was also a 2-min break every 12–13 min (depending on a given participant's own pace), during which the experimenter checked the impedances and rewetted the sensors. Each session lasted for approximately 1.5 h.

4.4. Electrophysiological acquisition and processing

Continuous EEG was recorded with a 128-channel Hydrocel GSN SensorNet (Tucker et al., 1994) using the EGI system and the NetStation Recording software (EGI Inc., Eugene, OR). The EEG was amplified and digitized at 250 Hz, and referenced to vertex during recording. The impedances were kept below 40kΩ throughout recording.

Data processing was done with Brain Vision Analyzer 2.0. The raw EEG data in the NetStation format were converted to the Brain Vision format using the EEGLab software (Delorme and Makeig, 2004). The EEG data were re-referenced off-line to the average of the left and right mastoids, and low-pass filtered at 30 Hz (48 dB/oct slope). Blinks and horizontal eye movements were detected and corrected via Independent Component Analysis (ICA) using the Infomax algorithm (Makeig et al., 1997). The data were segmented from 200 ms before the target word onset to 1000 ms after, with the baseline correction from −200 to 0 ms preceding the target word onset. Segments were rejected when they contained signals exceeding ± 100 μV within the segment. The accepted trials were averaged for each condition for each participant, for generating grand averages.

4.5. Statistical analysis

We conducted two statistical analyses: (1) The first one focused on the N400 component, using an *a priori* time window from 200 to 500 ms at the frontal and posterior locations. (2) The second one captured the temporal dynamics, using 100 ms consecutive time windows from 200 to 500 ms. This was because past concreteness studies used very different time windows as their frontal N400 (200–450 ms in Barber et al. (2013), 350–380 ms in Adorni and Proverbio (2012), 300–550 ms in West and Holcomb (2000), and 390–590 ms in Kanske and Kotz (2007)). While the slight time differences between effects in different studies could reflect qualitatively similar effects that were quantitatively different due to different amount of conditional differences across studies, it is also possible the time differences reflect differential underlying neurogenerators.

The Greenhouse–Geisser sphericity correction (Greenhouse and Geisser, 1959) was applied to reported p values when $df > 1$. In cases where multiple comparisons were carried out, the p-values were further corrected based on the False Discovery Rate (FDR) procedure (Benjamini and Hochberg, 1995).

5. Declarations of interest

None.

Acknowledgement

Supported by NIH/NIDCD R01 DC010783 (RHD). We thank John Richards for help with EEG equipment.

Disclosure of interest statement

The authors report no conflict of interest.

References

Adorni, R., Proverbio, A.M., 2012. The neural manifestation of the word concreteness effect: an electrical neuroimaging study. Neuropsychologia 50 (5), 880–891.
Barber, H.A., Otten, L.J., Kousta, S.T., Vigliocco, G., 2013. Concreteness in word processing: ERP and behavioral effects in a lexical decision task. Brain Lang. 125 (1), 47–53.
Bardolph, M., Coulson, S., 2014. How vertical hand movements impact brain activity elicited by literally and metaphorically related words: an ERP study of embodied metaphor. Front. Hum. Neurosci. 8, 1031.
Benjamini, Y., Hochberg, Y., 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. J. Roy. Stat. Soc. B Methodol. 289–300.
Beretta, A., Fiorentino, R., Poeppel, D., 2005. The effects of homonymy and polysemy on lexical access: an MEG study. Cognitive Brain Res. 24 (1), 57–65.
Blasko, D.G., Connine, C.M., 1993. Effects of familiarity and aptness on metaphor processing. J. Exp. Psychol. Learn. Mem. Cogn. 19 (2), 295.
Boulenger, V., Roy, A.C., Paulignan, Y., Deprez, V., Jeannerod, M., Nazir, T.A., 2006. Cross-talk between language processes and overt motor behavior in the first 200 msec of processing. J. Cognit. Neurosci. 18 (10), 1607–1615.
Boulenger, V., Shtyrov, Y., Pulvermüller, F., 2012. When do you grasp the idea? MEG evidence for instantaneous idiom understanding. Neuroimage 59 (4), 3502–3513.
Bowdle, B.F., Gentner, D., 2005. The career of metaphor. Psychol. Rev. 112 (1), 193.
Brysbaert, M., New, B., 2009. Moving beyond Kučera and Francis: a critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. Behav. Res. Methods 41 (4), 977–990.
Citron, F.M., Goldberg, A.E., 2014. Metaphorical sentences are more emotionally engaging than their literal counterparts. J. Cognit. Neurosci. 26 (11), 2585–2595.
Coulson, S., Matlock, T., 2001. Metaphor and the space structuring model. Metaphor Symbol 16 (3–4), 295–316.
Coulson, S., Van Petten, C., 2002. Conceptual integration and metaphor: an event-related potential study. Memory Cognition 30 (6), 958–968.
Dalla Volta, R., Fabbri-Destro, M., Gentilucci, M., Avanzini, P., 2014. Spatiotemporal dynamics during processing of abstract and concrete verbs: an ERP study. Neuropsychologia 61, 163–174.
De Grauwe, S., Swain, A., Holcomb, P.J., Ditman, T., Kuperberg, G.R., 2010. Electrophysiological insights into the processing of nominal metaphors. Neuropsychologia 48 (7), 1965–1984.
Delorme, A., Makeig, S., 2004. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics. J. Neurosci. Methods 134, 9–21.
Desai, R.H., Binder, J.R., Conant, L.L., Mano, Q.R., Seidenberg, M.S., 2011. The neural career of sensory-motor metaphors. J. Cognit. Neurosci. 23 (9), 2376–2386.
Desai, R.H., Conant, L.L., Binder, J.R., Park, H., Seidenberg, M.S., 2013. A piece of the action: modulation of sensory-motor regions by action idioms and metaphors. NeuroImage 83, 862–869.
Forgács, B., Bardolph, M.D., Amsel, B.D., DeLong, K.A., Kutas, M., 2015. Metaphors are physical and abstract: ERPs to metaphorically modified nouns resemble ERPs to abstract language. Front. Hum. Neurosci. 9, 28.
Frazier, L., Rayner, K., 1990. Taking on semantic commitments: processing multiple meanings vs. multiple senses. J. Mem. Lang. 29 (2), 181–200.
Frisson, S., Pickering, M.J., 1999. The processing of metonymy: evidence from eye movements. J. Exp. Psychol. Learn. Mem. Cogn. 25 (6), 1366.
Frisson, S., Pickering, M.J., 2001. Processing ambiguous verbs: evidence from eye movements. J. Exp. Psychol. Learn. Mem. Cogn. 27 (2), 556.
Gallese, V., Lakoff, G., 2005. The brain's concepts: the role of the sensory-motor system in conceptual knowledge. Cognitive Neuropsychol. 22 (3–4), 455–479.
Gentner, D., Bowdle, B., Wolff, P., Boronat, C., 2001. Metaphor is like analogy. Anal. Mind: Perspectives Cognitive Sci. 199–253.
Gerring, R.J., Healy, A.F., 1983. Dual processes in metaphor understanding: comprehension and appreciation. J. Exp. Psychol. Learn. Mem. Cogn. 9 (4), 667.
Gibbs Jr, R.W., 1996. Why many concepts are metaphorical. Cognition 61 (3), 309–319.
Greenhouse, S.W., Geisser, S., 1959. On methods in the analysis of profile data. Psychometrika 24 (2), 95–112.
Grice, H.P., 1975. Logic Conv. 1975, 41–58.
Hauk, O., Davis, M.H., Ford, M., Pulvermüller, F., Marslen-Wilson, W.D., 2006. The time course of visual word recognition as revealed by linear regression analysis of ERP data. Neuroimage 30 (4), 1383–1400.
Holcomb, P.J., Kounios, J., Anderson, J.E., West, W.C., 1999. Dual-coding, context-availability, and concreteness effects in sentence comprehension: an electrophysiological investigation. J. Exp. Psychol. Learn. Mem. Cogn. 25 (3), 721.
Huang, H.W., Lee, C.L., Federmeier, K.D., 2010. Imagine that! ERPs provide evidence for distinct hemispheric contributions to the processing of concrete and abstract concepts. NeuroImage 49 (1), 1116–1123.
Kanske, P., Kotz, S.A., 2007. Concreteness in emotional words: ERP evidence from a hemifield study. Brain Res. 1148, 138–148.
Keysar, B., 1989. On the functional equivalence of literal and metaphorical interpretations in discourse. J. Mem. Lang. 28 (4), 375–385.
Kim, A., Lai, V., 2012. Rapid interactions between lexical semantic and word form analysis during word recognition in context: evidence from ERPs. J. Cognit. Neurosci. 24 (5), 1104–1112.
Kutas, M., Federmeier, K.D., 2011. Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). Annu. Rev. Psychol. 62, 621–647.
Lacey, S., Stilla, R., Sathian, K., 2012. Metaphorically feeling: comprehending textural metaphors activates somatosensory cortex. Brain Lang. 120 (3), 416–421.
Lai, V.T., Curran, T., 2013. ERP evidence for conceptual mappings and comparison processes during the comprehension of conventional and novel metaphors. Brain Lang. 127 (3), 484–496.
Lai, V.T., Curran, T., Menn, L., 2009. Comprehending conventional and novel metaphors: an ERP study. Brain Res. 1284, 145–155.
Lakoff, G., Johnson, M., 1999. Philosophy in the Flesh. Basic books, New york.
Lauro, L.J.R., Mattavelli, G., Papagno, C., Tettamanti, M., 2013. She runs, the road runs, my mind runs, bad blood runs between us: literal and figurative motion verbs: an fMRI study. NeuroImage 83, 361–371.
Mahon, B.Z., Caramazza, A., 2008. A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. J. Physiol. 102 (1–3), 59–70.
Makeig, S., Jung, T.P., Bell, A.J., Ghahremani, D., Sejnowski, T.J., 1997. Blind separation of auditory event-related brain responses into independent components. Proc. Natl. Acad. Sci. 94 (20), 10979–10984.
McElree, B., Pylkkänen, L., Pickering, M.J., Traxler, M.J., 2006. A time course analysis of

enriched composition. Psychon. Bull. Rev. 13 (1), 53–59.
Murray, M.M., Brunet, D., Michel, C.M., 2008. Topographic ERP analyses: a step-by-step tutorial review. Brain Topogr. 20 (4), 249–264.
Oldfield, R.C., 1971. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 9 (1), 97–113.
Pylkkänen, L., Llinás, R., Murphy, G.L., 2006. The representation of polysemy: MEG evidence. J. Cognit. Neurosci. 18 (1), 97–109.
Schmidt-Snoek, G.L., Drew, A.R., Barile, E.C., Agauas, S.J., 2015. Auditory and motion metaphors have different scalp distributions: an ERP study. Front. Hum. Neurosci. 9, 126.
Searle, J.R., 1975. Indirect speech acts. Syntax & Semantics, 3: Speech Act, 59–82.
Tucker, D.M., Liotti, M., Potts, G.F., Russell, G.S., Posner, M.I., 1994. Spatiotemporal analysis of brain electrical fields. Hum. Brain Mapp. 1, 134–152. https://doi.org/10.1002/hbm.460010206.
Weiland, H., Bambini, V., Schumacher, P.B., 2014. The role of literal meaning in figurative language comprehension: evidence from masked priming ERP. Front. Hum. Neurosci. 8, 583.
West, W.C., Holcomb, P.J., 2000. Imaginal, semantic, and surface-level processing of concrete and abstract words: an electrophysiological investigation. J. Cognit. Neurosci. 12 (6), 1024–1037.