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Flexibility in Embodied Language Processing: Context Effects in Lexical Access

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Abstract

According to embodied theories of language (ETLs), word meaning relies on sensorimotor brain areas, generally dedicated to acting and perceiving in the real world. More specifically, words denoting actions are postulated to make use of neural motor areas, while words denoting visual properties draw on the resources of visual brain areas. Therefore, there is a direct correspondence between word meaning and the experience a listener has had with a word's referent on the brain level. Behavioral and neuroimaging studies have provided evidence in favor of ETLs; however, recent studies have also shown that sensorimotor information is recruited in a flexible manner during language comprehension (e.g., Raposo et al. 2009; Van Dam et al., 2012), leaving open the question as to what level of language processing sensorimotor activations contribute. In this study, we investigated the time course of modality-specific contributions (i.e., the contribution of action information) as to word processing by manipulating both (a) the linguistic and (b) the action context in which target words were presented. Our results demonstrate that processes reflecting sensorimotor information play a role early in word processing (i.e., within 200 ms of word presentation), but that they are sensitive to the linguistic context in which a word is presented. In other words, when sensorimotor information is activated, it is activated quickly; however, specific words do not reliably activate a consistent sensorimotor pattern.

Keywords: Embodiment; Semantics; Action; Conceptual flexibility; P2; Lexical access

1. Introduction

According to embodied theories of language (ETLs), the meaning of words is conveyed by means of re-activating experiential traces in sensorimotor brain regions (e.g.,

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visual and motor systems) (Hoenig et al., 2011; Kiefer, Sim, Herrnberger, Grothe, & Hoenig, 2008). A number of different theoretical proposals have been put forth within the general embodied framework (e.g., Mahon & Caramazza, 2008; Vigliocco, Vinson, Lewis, & Garrett, 2004; Barsalou, 1999, 2008). These proposals differ from each other in the role they ascribe to sensorimotor brain areas in representing meaning (for a review, see Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012), but they all share the notion that sensorimotor experience influences the cognitive architecture of the language system. One way to better understand the level of processing to which sensorimotor activations contribute (e.g., early word recognition vs. later word integration) is to investigate the time course of embodied effects during word processing in various contexts. In this study we investigated the time course of these effects using event-related potentials (ERPs).

There is ample behavioral and neuroimaging evidence for the stance that language comprehension shares mechanisms with perception and action. For example, it has been shown that comprehending sentences and single words denoting actions can facilitate the execution of a congruent action (Glenberg & Kaschak, 2002; Rueschemeyer, Pfeiffer, & Bekkering, 2010; Van Dam, Rueschemeyer, Lindemann, & Bekkering, 2010). Neuroimaging studies have provided evidence that comprehending sentences denoting motor acts (Tettamanti et al., 2005; Desai, Binder, Conant, & Seidenberg, 2010), verbs that entail a motor component (Hauk, Johnsrude, & Pulvermueller, 2004; Hauk & Pulvermueller, 2004a; Van Dam, Rueschemeyer, & Bekkering, 2010) and words denoting manipulable objects (Boronat et al., 2005; Chao & Martin, 2000; Rueschemeyer, Rooij, Lindemann, Willems, & Bekkering, 2010; Saccuman et al., 2006) activate the cerebral motor system. On the basis of behavioral and neuroimaging data it has been argued that strong functional links exist between the neural motor system and lexical-semantic processing of words that entail a motor component.

Pulvermueller and colleagues have proposed that since actions and their referents often co-occur near-simultaneously, neural populations recruited for processing a word and those involved in processing the referent body movement frequently fire together and become strongly linked (Pulvermueller, 1999, 2001). Due to the strong within-assembly connections that link language and action representations, action word recognition will, therefore, automatically trigger activation in specific action-related networks. In this strong embodied account, lexically driven visual and motor activations are argued to be automatically triggered upon encountering a word. In support of this view, it has been demonstrated that category-specific activation can be observed as early as ~200 ms after word onset (Hauk & Pulvermueller, 2004a; Pulvermueller, Härle, & Hummel, 2000), it occurs in a paradigm in which subjects had to focus their attention on a distractor task (Pulvermueller & Shtyrov, 2006, 2009; Shtyrov, Hauk, & Pulvermueller, 2004), and also occurs for action verbs embedded within idiomatic phrases like "grasp an idea" (Boulenger, Hauk, & Pulvermueller, 2009).

However, the automaticity of motor-related activity for action words has been challenged by several studies that failed to find motor-related activity for words with an action-semantic component (Raposo, Moss, Stamatakis, & Tyler, 2009; Rueschemeyer, Brass, & Friederici, 2007). A recent fMRI study by Raposo et al. (2009) showed that action verbs in isolation (e.g., *kick*) and in a literal sentence (e.g., *kick the ball*) elicited a response in motor/premotor cortices. No action-related activity was observed for action verbs in idiomatic contexts (e.g., *kick the bucket*). In a similar vein, Rueschemeyer et al. (2007) showed that processing morphologically complex verbs built on motor stems (i.e., *begreifen*: to comprehend) showed no differences in involvement of the motor system when compared with processing complex verbs with abstract stems (e.g., *bedenken*: to think). These findings strongly challenge the automaticity of motor-related activity for action words and suggest that the activation of meaning attributes of words is a flexible and contextually dependent process. Van Dam, van Dijk, Bekkering, and Rueschemeyer (2012) showed in a recent fMRI study that the neural signature of a concept differs depending on which features of the concept are emphasized by the context (see also Hoenig, Sim, Bochev, Herrnberger, & Kiefer, 2008; Tousignant & Pexman, 2012). These findings have been taken as evidence that conceptual features contribute to word meaning to varying degrees in a flexible context-dependent manner.

One of the greatest strengths of human language is that words can be used in a flexible manner; that is, word meaning is often dependent on the context in which a word is presented. Barsalou (1982) proposed that concepts are formed both by context-independent and context-dependent properties. That is, on one hand, context-independent properties form the core meaning of a concept and are activated by the word on all occasions. On the other hand, conceptual flexibility can be realized by context-dependent properties that are only activated by relevant contexts in which the word appears. Kiefer and Pulvermueller (2012) argue that in contrast to classical semantic models which entail a localist representation format of concepts, distributed semantic memory models can provide the basis for conceptual flexibility. In these models, concepts are considered to be built on multiple representational units, which can contribute to a concept varying as a function of the context in which a concept is accessed. To determine whether contextual effects are already reflected in early processes (i.e., lexical access/selection) or rather in late processes (integration) requires a detailed understanding of the temporal dynamics of these effects.

This study was designed to explore the temporal dynamics of action effects on word processing. Importantly, previous work has shown (a) that action preparation can prime the comprehension of words with a congruent action association (e.g., the preparation of a hand movement toward the body facilitates recognition of a word such as *cup*; Helbig, Graf, & Kiefer, 2006; Helbig, Steinwender, Graf, & Kiefer, 2010; Rueschemeyer, Pfeiffer, et al., 2010; Rueschemeyer, Rooij, et al., 2010), and (b) that these priming effects can be overridden if the target word is presented in the context of another word which suggests a non-canonical use of the object denoted by the target word (e.g., the preparation of a hand movement toward the body does not facilitate the recognition of the word *cup* in the word pair *sink-cup*; Bub & Masson, 2010; van Dam, Rueschemeyer, & Bekkering, 2010; van Dam, Rueschemeyer, Lindemann et al., 2010; for a review see Willems & Casasanto, 2011). This indicates that action primes do not facilitate the processing of words with putative action features consistently: *cup* in the context of *coffee* is an object affording a movement of the hand toward the body, whereas *cup* in the context of *sink* is an object affording a movement of the hand away from the body. It remains unclear, however, whether the incongruence between the prepared action and the target word in an incongruent word pair is experienced early or late during target word recognition. In other words, is access to the target word (i.e., an early stage in lexical processing) modulated by the action prime, or is integration of the target word into the surrounding context modulated by the action prime (i.e., a later stage in lexical processing)?

To investigate whether the observed contextual effects on word processing reflect changes in early processes (i.e., lexical access/selection) or late processes (i.e., integration), we used the same stimuli as van Dam, Rueschemeyer, & Bekkering, 2010; van Dam, Rueschemeyer, Lindemann, et al., 2010. The goals of our study were the following: First, we aimed to go beyond the previous behavioral results by showing that event-related brain potentials (ERPs) are modulated by the congruency of the combination of a context prime and target word with a prepared movement. Secondly, we sought to determine whether such an effect of context on embodied word processing is the result of an influence on early (i.e., lexical access/selection) or late processes (i.e., semantic integration) in word processing and if this effect is reflected by the ERPs corresponding to each of the stages.

Most studies have used the effects of word frequency, lexicality, and word regularity to investigate the speed and ease with which an orthographic word form uniquely activates its corresponding representation in the mental lexicon. The idea being that, the speed of word identification is influenced by the frequency with which a word occurs in a text corpus: with people being faster to identify high- versus low-frequency words. In a similar vein, it has been shown that participants are faster in the naming of regular as compared with exception words and that participants are faster in naming words as compared with pseudowords (i.e., words with or without a lexical frequency). Word frequency, lexicality, and word regularity are, therefore, often used as indicators of the ease of lexical access. In addition, several studies have indicated that lexical access can be indexed by early ERP components. Smaller amplitudes are typically observed for high-frequency words as compared with low-frequency words in the N1 (Assadollah & Pulvermueller, 2001; Hauk & Pulvermueller, 2004b; Penolazzi, Hauk, & Pulvermueller, 2007; Sereno, Brewer, & O'Donnell, 2003) and in the P2 component (Dambacher, Kliegl, Hofmann, & Jacobs, 2006; Shtyrov, Kimppa, Pulvermueller, & Kujala, 2011; Strijkers, Costa, & Thierry, 2010). In addition, Hauk, Davis, Ford, Pulvermueller, and Marslen-Wilson (2006) showed that the N1 component is modulated by lexicality, reflected by smaller amplitudes for words than for pseudowords. In a similar vein, it has been shown that the P2 component is modulated by word regularity (Sereno, Rayner, & Posner, 1998), the semantic correctness of stimuli (Martin-Loeches, Hinojosa, Gómez-Jarabo, & Rubia, 1999), and orthography and synonymy (Liu, Jin, Qing, & Wang, 2011). The studies mentioned above provide evidence for an early time line of lexical processing during reading, making both the N1 and P2 component a valid index of lexical access.

Alternatively, the context in which a word is presented might mainly play a role in later processes related to the integration of a spoken or written word into a meaning representation of the local sentence context within which it occurs (indexed by the N400).

Semantic integration is generally indexed by the N400 effect. It has been shown that the semantic relationship between a prime and a target modulates the amplitude of the N400 to the target (Brown & Hagoort, 1993; Kutas & Hillyard, 1980; McCarthy & Nobre, 1993). In a similar vein, the N400 has been shown to be modulated by the congruency between a sentence final word and the preceding sentence (Hagoort, Hald, Bastiaansen, & Petersson, 2004). These findings suggest that the N400 is a valid marker of the process of integrating incoming lexical-semantic knowledge and the local sentence context.

2. Experiment

2.1. Method

2.1.1. Participants

Thirty-one right-handed subjects participated (11 males); the average age was 20.9 years (SD = 1.90). The data from five participants were excluded because of excessively slow reaction times (RT > mean + 2 × SD) or an excessive number of errors. All subjects were students at the Radboud University Nijmegen and participated either for money or course credit. No subject was aware of the purpose of the experiment.

2.1.2. Apparatus and stimuli

Participants were sitting at a viewing distance of about 100 cm; the average length of the presented words was 10 letters (corresponding to an average size of 1.0 × 5 cm). A total of 120 letter string stimuli were created for the experiment (stimuli with English translations can be seen in Table 1). Eighty were real Dutch words denoting familiar objects and comprised the critical experimental stimuli. The remaining 40 stimuli were Dutch pseudowords (i.e., phonotactically and orthographically legal letter strings with no meaning in Dutch). Critical stimuli belonged to one of the two experimental conditions: (a) words denoting objects for which the typical use is associated with a movement toward the body (e.g., *telephone, photo camera*), and (b) words denoting objects for which the typical use is associated with a movement away from the body (e.g., *hammer, pencil*). The critical word stimuli were matched for word length, frequency, and imageability (see Table 2). Critical stimuli were presented in two contexts: (a) critical words were preceded by a word that emphasized the action feature related to the typical use (e.g., *conversation-telephone, nail-hammer*), and (b) critical words were preceded by a word that emphasized an action feature not related to the typical use (e.g., *adapter-telephone, tool belt-hammer*). That is, in the case that the critical word was preceded by a prime word not related to the typical use of the object, this yielded a context characterized by an action in the opposite direction as that yielded by the combination between the critical word and a prime that emphasized the typical use of the object. Pseudowords were also presented twice, with two different preceding "context" words.

We tested the validity and psycholinguistic properties of the experimental stimuli using a pretest questionnaire that we administered to 15 native Dutch speakers who did not par-

Table 1
Dutch words associated with a movement toward the body (body words) and a movement away from the body (world words)

Body Words		World Words	
Haarband	*Hair ribbon/Hairband*	Zwabber	*Swab/Mop*
La	*Drawer*	Spaarpot	*Money box*
Sjaal	*Scarf*	Spade	*Spade/Shovel*
Microfoon	*Microphone*	Zaag	*Saw*
Loep	*Magnifying glass*	Vaas	*Vase*
Hoed	*Hat*	Naald	*Needle*
Nagelvijl	*Nail file*	Kaars	*Candle*
Pleister	*Band-Aid*	Plant	*Plant*
Fluit	*Flute*	Flesopener	*Bottle opener*
Bril	*(pair of) Spectacles*	Deegroller	*Rolling pin*
Wijnglas	*Wine glass*	Koekenpan	*Frying pan*
Mok	*Mug*	Voetbal	*Football*
Make-up	*Make up*	Theepot	*Teapot*
Zakdoek	*Handkerchief*	Speld	*Pin*
Lolly	*Lollipop*	Stempel	*Stamp*
Halssnoer	*Necklace*	Sleutel	*Key*
Helm	*Helmet*	Lamp	*Lamp*
Telefoon	*Telephone*	Schep	*Scoop/Shovel*
Shampoo	*Shampoo*	Knikker	*Marble*
Armband	*Bracelet*	Bijl	*Axe*
Tondeuse	*(pair of) Clippers*	Baksteen	*Brick*
Mondharmonica	*Mouth organ*	Fakkel	*Torch*
Want	*Mitten*	Bel	*Bell*
Tandenborstel	*Toothbrush*	Hamer	*Hammer*
Handdoek	*Towel*	Computer	*Computer*
Ring	*Ring*	Hengel	*Fishing rod*
Trompet	*Trumpet*	Pen	*Pen*
Schoen	*Shoe*	Boor	*Drill*
Lippenstift	*Lipstick*	Gloeilamp	*Lightbulb*
Lepel	*Spoon*	Trommel	*Drum*
Oorbel	*Earring*	Kapstok	*Coat rack*
Borstel	*Brush*	Verfpot	*Pot/Tin of paint*
Verrekijker	*Binoculars*	Vergiet	*Strainer/Colander*
Stropdas	*Tie/Necktie*	Karaf	*Decanter/Carafe*
Gordel	*Belt*	Garde	*Whisk*
Vork	*Fork*	Paraplu	*Umbrella*
Parfum	*Perfume*	Mes	*Knife*
Horloge	*Watch*	Potlood	*Pencil*
Jas	*Jacket*	Ventilator	*Fan*
Fototoestel	*Photo camera*	Dobbelsteen	*Dice*

Note. English translations are printed in italics.

Table 2
Mean ratings of the pre-tests

	Body Words	World Words
Length	6.8	6.3
Lemma frequency per million (CELEX)	567	487
Imageability	6.82	6.76
Action association	−1.33	2.33

ticipate in the electroencephalogram (EEG) experiment (see Table 3 for results). In this questionnaire, participants were asked to rate critical stimuli on a 7-point scale with respect to (a) the imageability of the noun (1 = very difficult to imagine the referent noun, 7 = very easy to imagine the referent noun), (b) whether the noun denoted an object that you typically bring toward or away from the body (−3 = toward the body, +3 = away from the body). In addition, we administered a posttest questionnaire to 12 native Dutch speakers who did not participate in the EEG experiment. In this questionnaire, participants rated critical stimuli with respect to (c) whether the noun presented in a context that emphasized the typical use of the object versus a context that emphasized an action feature not related to the typical use was judged to be associated with a movement toward or away from the body (1 = toward the body, 7 = away from the body). The results of the questionnaires indicated that words were matched across the two conditions with respect to imageability (Body: $M = 6.82$,SE = .024; World: $M = 6.76$, SE = .029), $t(1,78) = 1.46$, $p > .1$. In order to obtain an objective measure of word frequency, we calculated the mean lemma frequency per million for each condition using the lexical database (Baayen, Piepenbrock, & van Rijn, 1993). This gave a mean of 567 (SE = 128.3) for the body words and 487 (SE = 119.3) for the world words. An independent sample *t* test indicated words were matched on frequency, $t(1,78) = 1.48$, $p > .1$. Additionally, independent sample *t* tests indicated that nouns were matched with regard to length (Body: $M = 6.8$, World: $M = 6.3$), $t(1,78) = 0.90$, *p*s > .2. Importantly, participants consistently indicated that body words referred to objects that you typically bring toward the body, world words referred to objects you typically bring away from the body (Body: $M = -1.13$, $SE = .049$; World: $M = 2.33$, $SE = .057$), and both means significantly differed from 0 as indicated by one-sample *t* tests (all *p*s < .001). Furthermore, participants indicated that body words presented in a context that emphasized the typical use of the object referred to objects you typically bring toward the body, body words presented in a context that emphasized an action feature not related to the typical use of the object referred to objects you bring away from the body (body word in dominant context: $M = 2.00$, $SE = .189$; body word in non-dominant context: $M = 4.97$, $SE = .296$). A paired samples *t* test indicated that direction ratings for body words significantly differed as a function of context, $t(1,11) = 7.02$, $p < .001$. In addition, participants indicated that world words presented in a context that emphasized the typical use of the object referred to objects you typically bring away from the body, world words presented in a context that emphasized an action feature not related to the typical use of the object referred to

Table 3
Average performance rates (PR) and reaction times (RTs) with standard error for congruent and incongruent trials in both the dominant focus and non-dominant focus condition

	Dominant focus		Non-dominant focus	
	PR(SE)	RT(SE)	PR(SE)	RT(SE)
Congruent	95.4 (.94)	620 (16.00)	95.2 (.86)	619 (16.08)
Incongruent	96.6 (.71)	616 (15.28)	95.6 (.73)	624 (14.64)

objects you bring toward the body (world word in dominant context: M = 4.60, SE = .240; world word in non-dominant context: M = 3.87, SE = .133). A paired samples *t* test indicated that direction ratings for world words significantly differed as a function of context, t(1,11) = 2.80, $p < .050$.

2.1.3. Procedure and design

Participants were seated comfortably in front of a computer monitor and responded by means of a key press (i.e., by using their right hand to press a key that was located *nearer* or *further* from the body). To start a trial participants had to press the start button of a response device (located in the middle of the response device). Subsequently, they received a cue (i.e., an A or B) that signaled them to prepare a movement (either *toward* or *away* from the body), which they only executed if the second word was lexically valid. Participants were instructed to read both words carefully. The advent of the two words was signaled by a fixation point (a plus sign appearing for 500 ms) at screen center. The first word was presented for 1,000 ms. The second word appeared 1,000 ms after the first word, calling for a response to the identity of the word (i.e., a response in the case that the second word was a real word in Dutch). The second word remained visible until participants responded, or for a maximum of 2,000 ms (Fig. 1). The experi-

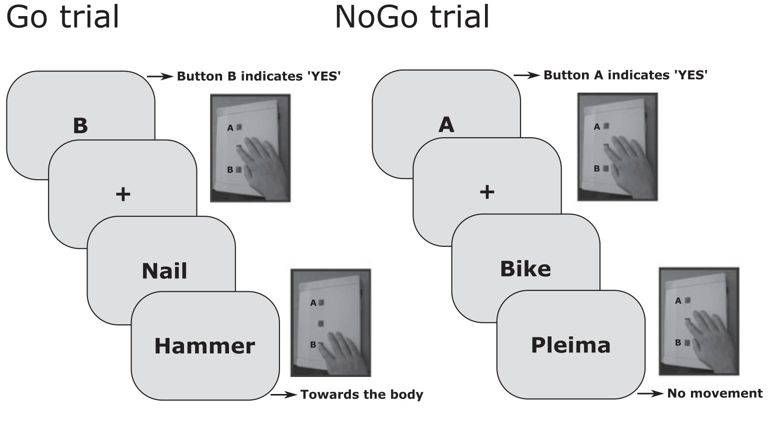

Fig. 1. Overview of the display and the timing of events.

ment was comprised of 240 trials: 160 experimental trials composed by 20 replications of the factorial combination of two movement cues, two word types and two contexts, and 80 pseudoword trials. During the experimental session both EEG and behavioral data were obtained. The order in which word pairs were presented was counterbalanced over participants. That is, half of the participants first saw a critical word (e.g., *telephone*) preceded by a word that emphasized the dominant action feature (*conversation*) and then the same critical word preceded by a word that emphasized a non-dominant action feature (*adapter*) and vice versa.

2.2. EEG data acquisition

The EEG was recorded continuously while the task was performed with 27 tin electrodes mounted in an elastic electrode cap (Electrocap International, Ohio, USA). Electrodes were placed at 7 midline (FPz/AFz/FCz/Cz/Pz/Oz) and 20 lateral (FP1-2/F7-8/F3-4/FC5-6/T3-4/C3-4/CP5-6/T5-6/P3-4/O1-2) locations in the extended international 10/20 system (Sharbrough et al., 1991). The signals were referenced to the left mastoid and were digitized with a sampling rate of 200 Hz during acquisition. Eye movements were recorded by electro-oculogram (EOG). The horizontal EOG (HEOG) was recorded bipolarly from electrodes at the outer canthi of both eyes. The vertical electro-oculogram (VEOG) was the bipolar signal of above versus below the left eye. All electrode impedances were kept below 5 kΩ. The EEG and EOG signals were amplified using a time-constant of 8 seconds and were high-pass filtered at 0.02 Hz (24 dB/octave) during acquisition. For the analyses, the electrodes were rereferenced to the average of the linked mastoids and were filtered off-line with a low-pass filter set at 15 Hz (24 dB/octave). EEG data were analyzed using Brain Vision Analyzer (Brain Products, Munich, Germany).

2.2.1. Behavioral data analysis

Participants were trained to respond to the target words without looking at the response device. The accuracy of the response was emphasized, whereas the speed of responding was not emphasized. This was done for the reason that (a) reaction times (RTs) have been shown to be strongly related to P2 latency (Martin-Loeches et al., 1999) and (b) reaction time differences have already been obtained in a previous study using the exact same paradigm (van Dam, Rueschemeyer, Bekkering, 2010; van Dam, Rueschemeyer, Lindemann et al., 2010).

Average performance rates (percentage of trials correctly responded to) and RTs can be seen in Table 2. RTs were defined as the point in which participants recognized that a word was lexically valid (i.e., release of the start button). Additionally, we recorded movement times (i.e., the time from releasing the start button until depressing the target button). Responses to all trials were recorded and outliers ($2 \times$ STD $\pm$ mean RT) were excluded. Additionally, we excluded trials in which participants had extreme movement times ($2 \times$ STD $\pm$ mean MT). This led to an exclusion of 3.8% of the data. The significance criterion for all analyses was set to $p < .05$.

2.2.2. EEG data analyses

Trials were excluded from both the behavioral and the ERP analyses if participants responded incorrectly (4.3% of the data were excluded). Relevant trials were averaged to ERPs separately for each condition and each subject, relative to a 200 ms pre-stimulus baseline in a 1,200 ms epoch. EOG artifact correction was carried out using the procedure by Gratton, Coles, and Donchin (1983). Subsequently, we rejected ERP segments in which the voltage step between two consecutive sampling points was greater than 50 μV, the absolute difference between two values within the segment was greater than 75 μV, or the ERP segment contained a value that was smaller than −75 μV/bigger than 75 μV. On average, 32 trials were included in the Dominant Congruent condition (*SD* = 7.7), 32 trials in the Dominant Incongruent condition (*SD* = 6.3), 31 trials in the Non-dominant Congruent condition (*SD* = 7.4), and 32 trials in the Non-dominant Incongruent condition (*SD* = 7.3). The artifact-free ERP segments for each experimental condition were averaged within each participant. The N1 amplitude was measured as the most negative value within a 50–160 ms window following the presentation of the target stimulus. The P2 amplitude was measured as the most positive value within a 160–240 ms window following the presentation of the target stimulus (see Strijkers et al., 2010). The N400 amplitude was measured as the most negative value within a 300–400 ms window following the presentation of the target stimulus.

2.3. Generalized linear models

2.3.1. Behavioral data

RTs were averaged for each participant in each condition (see Table 2 for means) and submitted to a two-way repeated measures ANOVA with factors Action Congruency (congruent/incongruent) and Context (focus on dominant vs. non-dominant action feature). The main effect of Action Congruency and Context and the interaction between these factors failed to reach significance, all ps > .25.

Performance rates were averaged for each participant in each condition (see Table 2 for means) and submitted to a two-way repeated measures ANOVA with factors Action Congruency (congruent/incongruent) and Context (focus on dominant vs. non-dominant action feature). No significant differences in performance rates were detected (all ps > .25).

2.3.2. ERP data

For the ERP analyses, average EEG amplitude information was analyzed for two scalp regions of interest: left frontotemporal (FC5/CP5/T3/T5) and right frontotemporal (FC6/CP6/T4/T6).[1] Repeated measures ANOVAS were conducted on mean voltages with Context (focus on dominant vs. non-dominant action feature), Congruency (congruent vs. incongruent), and electrode site (four positions within the region of interest) as within subjects factors. Separate repeated measures ANOVAS were conducted for each time window and scalp region (Kiefer, Sim, Helbig, & Graf, 2011). The significance criterion for all the analyses was set to $p < .05$.

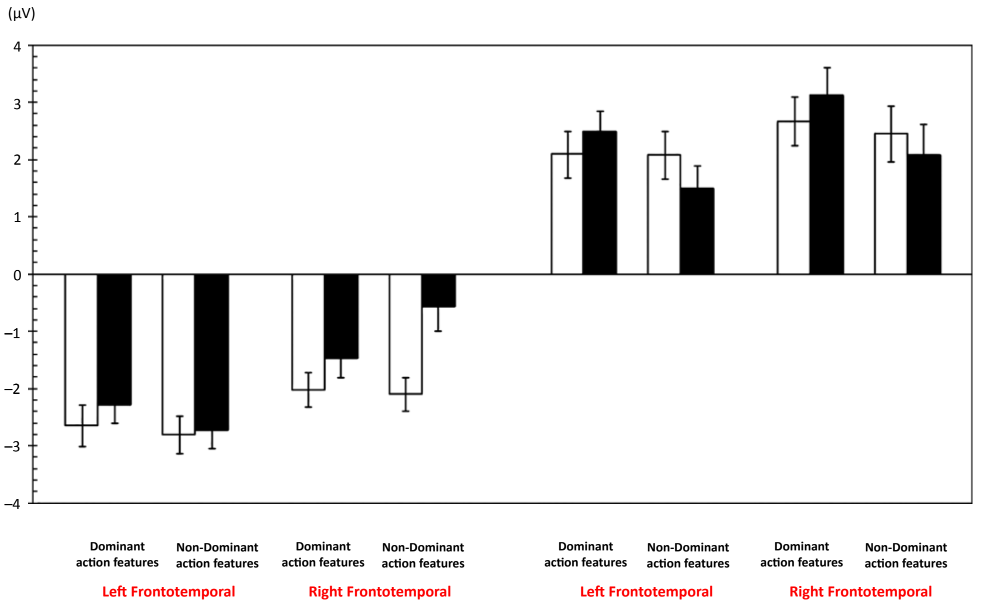

Fig. 2. Mean voltages in the N1 and P2 time window for processing words, as a function of the congruency between the cue and associated movement of the target word at left and right frontotemporal electrodes. Open bars, congruent trials; solid bars, incongruent trials.

2.3.3. Electrophysiological results

2.3.3.1. 50–160 ms after Target word onset (N1): In this early time window, we did not observe any reliable effect at left frontotemporal electrodes. At right frontotemporal electrodes, we obtained a significant effect of Action Congruency, $F(1,25) = 14.42$, $p = .001$, $MSE = 6.82$, $\eta^2_p = .366$, indicating that N1 amplitudes were bigger for congruent trials (*Mean* μ*V* = −1.73) than for incongruent trials (*Mean* μ*V* = −1.32). In addition, we obtained a marginally significant effect of Context, $F(1,25) = 3.56$, $p = .071$, $MSE = 4.82$, $\eta^2_p = .125$. Mean voltages in the N1 time window for the different experimental conditions are displayed in Fig. 2.

2.3.3.2. 160–240 ms after Target word onset (P2): In this early time window, we obtained a marginally significant main effect of Context, $F(1,25) = 4.00$, $p = .056$, $MSE = 7.63$, $\eta^2_p = .138$ at left frontotemporal electrodes, indicating that P2 amplitudes were bigger for trials in which there was a focus on dominant action features (*Mean* μ*V* = 2.29) than for trials in which there was a focus on non-dominant action features (*Mean* μ*V* = 1.79). More important, a significant Context × Action Congruency effect, $F(1,25) = 9.38$, $p = .005$, $MSE = 4.34$, $\eta^2_p = .273$ was found at left frontotemporal electrodes. To further explore this interaction, we calculated one-sided *post hoc* paired-sample *t* tests. For trials in which there was a focus on dominant action features P2 amplitudes were smaller for congruent trials (*Mean* μ*V* = 2.09) than for incongruent trials (*Mean* μ*V* = 2.48), $t(25) = 2.05$, $p = .026$. However, for trials in which there was a focus on

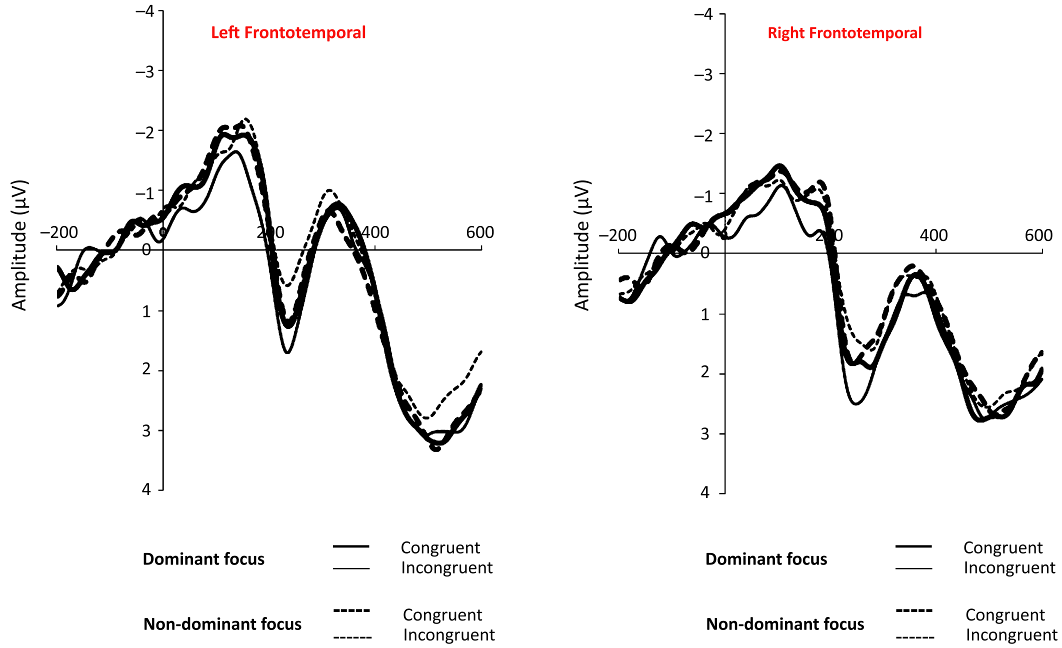

Fig. 3. Event-related waveforms for processing words, as a function of the congruency between the cue and associated movement direction, and the contextual focus (focus on dominant vs. non-dominant action feature). Depicted for left and right frontotemporal electrodes.

non-dominant action features P2 amplitudes were bigger for congruent trials (*Mean* µ*V* = 2.08) than for incongruent trials (*Mean* µ*V* = 1.48), $t(25) = 2.30$, $p = .015$. At right frontotemporal electrodes, we obtained a significant effect of Context, $F(1,25) = 5.44$, $p = .028$, $MSE = 10.08$, $\eta^2_p = .179$, indicating that P2 amplitudes were bigger for trials in which there was a focus on dominant action features (*Mean* µ*V* = 2.89) than for trials in which there was a focus on non-dominant action features (*Mean* µ*V* = 2.26). ERP waveforms as a function of the experimental conditions are displayed in Fig. 3. Mean voltages in the P2 time window for the different experimental conditions are displayed in Fig. 2.

2.3.3.3. 300–400 ms after Target word onset (N400): In this later time window, we did not observe a reliable effect of Context, Congruency, or an interaction between these two factors at left frontotemporal or right frontotemporal electrodes, all ps > .05.

3. Discussion

This study was designed to explore the temporal dynamics of contextual effects on embodied word processing. We investigated this by having participants perform a lexical decision task in which they had to prepare a response to words that denoted manipulable objects, presented either in a context that emphasized dominant versus non-dominant action features. The results of our experiment clearly demonstrate contextual effects on embodied word processing, evidenced by an Action Congruency × Context interaction effect. Specifically, at left frontotemporal electrodes higher P2 amplitudes were observed for trials in which the direction of the participant's response and the motor program typically associated with the word's referent do not correspond, but only if the context in which the word is presented highlighted the typical use of the object (e.g., *thirst*-cup). In a context that highlighted a less typical use of the object (e.g., *sink*-cup), we observed higher P2 amplitudes for trials in which the direction of the participant's response and the motor typically associated with the word correspond. These results are in line with the idea that motor activations are called on in a flexible manner during word processing (see also Hoenig et al., 2008; van Dam, Rueschemeyer, Bekkering, 2010; van Dam, Rueschemeyer, Lindemann et al., 2010; van Dam et al., 2012) and challenge the idea that lexically driven visual and motor activations are automatically triggered upon encountering a word. Moreover, these findings indicate that context can already have an effect on early processes of (embodied) word processing (i.e., lexical access/selection). In contrast with van Dam, Rueschemeyer, and Bekkering (2010) and van Dam, Rueschemeyer, Lindemann, et al. (2010), no effect was obtained in the reaction time measure obtained in this study. From pilot testing it became evident that participants had a lot of difficulty in being as fast as possible and at the same time keeping their eyes/head fixated at the center of the computer screen to minimize motion-induced artifacts in the EEG recording. Therefore, we decided to emphasize accuracy and not speed of the response when instructing our participants for the EEG experiment.

It should be noted, however, that the finding that motor activations are called on in a flexible manner during word processing might not necessitate any contribution of intended, controlled processes. According to the attentional sensitization model, conscious and unconscious perception are guided by similar computational principles and are susceptible to top-down modulation in a comparable manner, and this challenges the classical view of automaticity, according to which automatic processes are triggered invariantly and independently of the current configuration of the cognitive system (Kiefer & Martens, 2010). In this view, automaticity and context-dependent flexibility are thus not in conflict with one another.

In addition, we obtained a main effect of Congruency at right frontotemporal electrodes in the N1 time window. That is, N1 amplitudes are bigger for congruent trials (e.g., participant prepares a movement away from the body and then the word HAMMER is presented) than for incongruent trials. These findings seem to be in contrast with findings showing smaller amplitudes for high-frequency words (i.e., words that are easier to access) than for low-frequency words (Assadollah & Pulvermueller, 2001; Sereno et al., 2003). Looking at the mean voltages in the N1 time window (Fig. 2), however, it becomes apparent that the Action Congruency effects seem to be driven mainly by the condition in which there was a focus on non-dominant action features. Priming a participant with the non-dominant action features of an object seems to now increase the ease with which incongruent trials are processed. Our finding of smaller amplitudes for incongruent as compared to congruent trials at right frontotemporal electrodes within the N1 window, therefore, are in line with reports of smaller N1 amplitudes for high-frequency as compared with low-frequency words. In a similar vein, we observed a main effect of Context at left and right frontotemporal electrodes in the P2 time window. P2 amplitudes were larger for trials in which there was a focus on dominant action features than for trials in which there was a focus on non-dominant action features. Again, these findings seem to be in contrast with findings showing smaller amplitudes for high-frequency words than for low-frequency words (Dambacher et al., 2006; Strijkers et al., 2010). As for the Action Congruency effect in the N1 time window, the main effect of Context within the P2 time window is mainly driven by the incongruent condition. Priming a participant with the non-dominant action features of an object seems to increase the difficulty with which incongruent trials are processed. Our finding of larger amplitudes for incongruent trials within the P2 time window, therefore, is in line with reports of smaller P2 amplitudes for high-frequency as compared with low-frequency words.

The finding of an Action Congruency × Context interaction effect in the ERPs within 240 ms after word presentation is consistent with the time estimate of lexical access in word processing (Dambacher et al., 2006; Martin-Loeches et al., 1999; Sereno et al., 1998; Shtyrov et al., 2011; Strijkers et al., 2010). These findings seem to suggest that the preparation of a movement that is congruent with a target word can speed up lexical retrieval processes (evidenced by early differences in the P2 range), depending on the linguistic context in which a word is presented. These findings are in line with van Dam, Rueschemeyer, and Bekkering (2010) and van Dam, Rueschemeyer, Lindemann, et al., (2010), who showed that the effect of movement preparation on RTs in a lexical decision (LD) task interacted with the semantic context in which a word is encountered. These findings are also in line with Hoenig et al. (2008), who found even earlier effects (in the time range of the P1) of context on semantic processing.

Context effects in ERPs have been predominantly found in the time range approximately 400 ms after stimulus onset (Kutas & Federmeier, 2000). Typically, it has been demonstrated that in the N400 time range the ERP response to sentence final words is modulated by the congruency of the word with the preceding context, with semantically incongruent words eliciting a larger N400 than congruent words. Differences at this point are often interpreted as post-lexical and are argued to reflect contextual integration processes (Brown & Hagoort, 1993). A study by Sereno et al. (2003) presented participants with ambiguous sentence final words that were associated with both a low- and high-frequency meaning. The context of the preceding sentence was either neutral (therefore, biasing toward the high-frequency meaning) or biasing the low-frequency meaning (e.g., *James peered over at the bank* vs. *The mud was deep along the bank*). In the first sentence, the sentence final word is preceded by a neutral sentence (i.e., the dominant sense of the word is associated with *money*), whereas the final word in the second sentence is preceded by a sentence that biases toward its subordinate sense (i.e., *river*). Sereno et al. (2003) found that ambiguous words in a biasing context elicited amplitudes similar to those of low-frequency words, whereas in a neutral context, ambiguous words elicited amplitudes that resembled those of high-frequency words. These differences were observed in a time window from 132 to 192 ms post-stimulus, leading the authors to conclude that context has an early influence on lexical stages in word recognition.

In our present study we observed an Action Congruency × Context interaction. That is, target words elicited smaller amplitudes if the target word (e.g., *cup*) was congruent with the prepared movement (movement *towards* the body), but only if the word was presented in a language context highlighting the typical use of the object (e.g., *thirst*-**cup**). In a language context, highlighting a less typical use of the object (e.g., *sink*-**cup**), target words elicited higher amplitudes if the target word was congruent with the prepared movement. Smaller P2 amplitudes are typically observed for high-frequency words as compared with low-frequency words, and this P2 frequency effect is, therefore, assumed to reflect a difference in the speed of lexical access (with high-frequency words being lexically accessed very fast) (Dambacher et al., 2006). Our findings suggest that depending on the linguistic context, the preparation of a movement that is congruent with a target word can speed up lexical retrieval processes. Our findings extend findings by Sereno et al. (2003) by showing that lexical stages in word recognition are also influenced by a context that either emphasizes dominant or non-dominant conceptual features (i.e., the context prime does not change the meaning of the word *hammer*, but it does change the action features that become relevant to the concept).

4. Conclusion

In this study, we found an Action Congruency × Context interaction in the event-related brain potentials in the P2 range at left frontotemporal electrodes. Together the data suggest that language representations are flexible and context-dependent, and that the observed contextual effects on embodied word processing are already at play as early as at lexical stages in word recognition (indexed by the P2).

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A supplementary source of information was used in confirming our choice of electrodes for the analyses. To estimate the distribution of the loci of our ERPs, we transformed the grand average difference waves (congruent minus incongruent) using Low Resolution Electromagnetic Tomography method (LORETA; Pascual-Marqui, Michel, & Lehmann, 1994). The projections into LORETA space were used to create topographic distribution maps for these grand average difference waves. The topographic maps were estimated for the time interval 160–240 ms after target word onset, and the projections indicated that bilateral (fronto) temporal regions were involved for both the dominant and the non-dominant focus (see Figure S1). These temporal regions corresponded with the spatial locations of electrodes FC5/6, CP5/6, T3/4, T5/6. Note that the maps are only used for the purpose of visualizing distributions and do not represent the outcome of a complete source localization analyses.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. The image shows LORETA slices in Talairach space for the estimated activation differences (congruent compared with incongruent) both for the dominant (left) and the non-dominant (right) focus.